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Oil/Water Separator Test And Evaluation

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16. Abstract

Four oil/water separators were tested in 1992 in a project jointly sponsored by the U.S. Coast Guard R&D Center and the Marine Spill Response Corporation. The objective of the test program was to evaluate the performance of oil/water separators under a variety of conditions that replicated operating conditions expected during an offshore oil spill recovery operation. The separators tested were the Alfa-Laval OFPX 413 disk-stack centrifuge, Conoco Specialty Products' Vortoil Oilspill Separation System, International Separation Technology's Intr-Septor 250 and a simple gravity tank. Separation performance was documented for a range of influent oil/water ratios, using crude and a water-in-oil emulsion. Simulated sea motion, the addition of emulsion breaker, and debris in the influent were other variables included in the test program. Observations on separator operability, reliability, maintenance requirements, safety and transportability also were documented. Complete test results and analysis are included in the report. Recommended system improvements, based on manufacturers' input and performance analysis also are included. Test methods and parameters are fully documented in the report.

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EXECUTIVE SUMMARY

Introduction: From October - December 1992, the Naval Civil Engineering Laboratory (now the Naval Facilities Engineering Service Center, NFESC), conducted an evaluation of four oil/water separators at the Amoco oil refinery in Yorktown, Virginia. The project was jointly sponsored by the U.S. Coast Guard R&D Center and the Marine Spill Response Corporation (MSRC). The objective of the test program was to evaluate the performance of oil/water separators under a variety of conditions that replicated operating conditions expected during an offshore oil spill recovery operation.

Both the Coast Guard and MSRC are developing oil recovery systems that can be transported by land or air to the vicinity of an offshore spill and used on a vessel of opportunity available near the spill site. Oil/water separators could significantly improve the efficiency of recovery operations by increasing a recovery system's time in operation and effective recovery capacity, reducing transportation and storage requirements, and reducing waste handling and disposal costs. A separation system capable of breaking a water-in-oil emulsion is especially desirable. Breaking an emulsion would reduce the viscosity of the recovered product and improve pumpability, allow the recovered product to be reused, and enable burning. In order to discharge the water effluent stream from a separator used on site, the separator must be able to produce a water effluent clean enough to meet environmental regulations.

The original target specifications for a suitable oil/water separator included weight between 4,000 and 6,000 pounds, logistics footprint of 25 ft^2, logistics volume of 125 ft^3, and operating capacity range of 250 to 600 gpm. Three mechanical oil/water separators were selected for testing based on their capacity, weight and size, claimed separation ability, and the technology used to effect the separation. The separators selected for testing were the Alfa-Laval OFPX 413 disk-stack centrifuge system, Conoco Specialty Products' Vortoil Oilspill Separation System, incorporating a first stage surge tank and two stages of hydrocyclones, and International Separation Technology's Intr-Septor 250 centrifugal separator. A simple surge tank also was included in the test program to obtain data on water effluent quality to determine the value of including a surge tank as a first stage in a hybrid system with any of the other more sophisticated systems tested.

Test Series: Five test series were planned for each separator, with each series simulating different operating conditions expected at an offshore oil spill recovery site. Brief descriptions of the five test series are presented below:

1) Crude Oil Test. The purpose of this test was to determine the basic performance of the separator under the range of influent oil ratios that would be expected during skimming operations since influent ratios vary with oil layer thickness, and operational and environmental conditions.

2) Sea Motion Test. This test was included to determine the impact of sea motion on separator performance. This test replicated the full capacity tests of the Crude Oil Test with simulated sea motion.

3) Mousse Test. The purpose of this test was to quantify the impact of a viscous emulsion on separator operation because many oils emulsify before recovery operations can be completed.

4) Mousse With Emulsion Breaker Test. The purpose of this test was to determine if the combined effects of the separator and the emulsion breaker Exxon Breaxit 7877 were capable of freeing the water bound in emulsion.

5) Debris Test. The Debris Test was conducted with a sawdust and wood chip debris mixture added to the influent. This test was included since many separators are susceptible to clogging, and fibrous debris is typically encountered at spill recovery sites.

Oil Properties: Table 1 shows the target and actual properties for the crude oil and mousse used in the tests. All viscosity measurements were recorded at shear rate 10 sec^{-1}. The target properties were selected to represent the range of conditions that might be encountered at a marine spill over time. The oil used was Venezuelan crude BCF-17. This oil also was used to create the mousse.

TABLE 1: PETROLEUM PRODUCTS - TARGET AND ACTUAL PROPERTIES

Product:	Property:	Target Value:	Typical Actual Value:
Crude Oil	Viscosity:	1500 cP	500 - 1300 cP @ 16°C
	Specific Gravity:	0.90 - 0.98 (low end)	0.92
	Interfacial Tension:	N/A	3.9 - 43.5 dynes/cm (avg 25.0 dynes/cm)
Water-in Oil Emulsion ("Mousse")	Viscosity:	50,000 - 60,000 cP	2,000 - 36,000 cP (avg 20,000 cP @ 18°C
	Specific Gravity:	0.90 - 0.98 (high end)	0.93 - 0.98
	Entrained Water Volume:	60% - 70%	55% - 70%
	Interfacial Tension:	N/A	25.2 - 43.5 dynes/cm (avg 34.5 dynes/cm)

Separator Performance Summaries: Table 2 summarizes the principal of operation, system capacity, and transportability consideration for each separator included in the test program, compared to target specifications. The primary strengths and weaknesses of each separator tested are described in the following paragraphs. Table 3 summarizes separator performance for the Crude Oil and Mousse Tests.

TABLE 2: SEPARATOR PRINCIPAL OF OPERATION, SYSTEM CAPACITY AND TRANSPORTABILITY CONSIDERATIONS					
	Alfa-Laval	Surge Tank	Vortoil	Intr-Septor	Target Specification
Principle of Operation	Disk-Stack Centrifuge	Gravity Tank	Hydrocyclone	Centrifuge	N/A
Capacity (gpm)	65	250	250	155	250
Weight (lbs)	16,800	3,600	12,920	5,404	4,000 - 6,000
Weight/ Capacity (lbs/gpm)	258	14	52	35	8 - 24
Footprint (ft^2)	114	43	130	41	25
Volume (ft^3)	1080	214	769	195	125

TABLE 3: SEPARATOR PERFORMANCE SUMMARY				
	Alfa-Laval	Surge Tank	Vortoil	Intr-Septor
Maximum Water in Oil Effluent (Crude Oil Test)	67%	86%	0%	73%
Maximum Oil in Water Effluent (Crude Oil Test)	442 ppm	52%	178 ppm	3%
Maximum Free Water in Emulsion Effluent (Mousse Test)	92%	NOT TESTED	2%	97%
Maximum Emulsion in Water Effluent (Mousse Test)	5%	NOT TESTED	122 ppm	27%

Alfa-Laval OFPX 413: The Alfa-Laval's main strength is its ability to produce extremely pure water under most influent conditions. It also puts effluent streams out under pressure. This is advantageous in that additional pumps may not be required to transport oil effluent streams to storage devices, or for overboarding water effluent streams.

The primary weaknesses observed were the high weight to capacity ratio of the unit, the low water removal efficiencies observed for all influent conditions, and its inability to handle either a 100% oil or 100% water influent stream effectively. The system was susceptible to damage from the intake of debris, and debris also significantly decreased hydrocarbon removal performance.

Surge Tank: The only appreciable strength of the surge tank as configured for these tests is its light weight and low weight to capacity ratio. While water removal efficiencies were quite high under most influent conditions, with very little water in the oil effluent stream, the oil effluent flow rate was so low that no significant amount of oil was removed, resulting in poor effluent water quality. Hydrocarbon content of the effluent water was often equal to or poorer than that of the influent. Separation was also negatively impacted by simulated sea motion. The poor performance of the surge

tank is attributed to conducting 250 gpm tests on a modified unit originally designed for 100 gpm operation. Design modifications resulting from an analysis of the fluid flow hydraulics would improve performance. The surge tank test results should not be considered representative of the unmodified system if used at design capacity or of similar systems.

Vortoil Oilspill Separation System: The Vortoil Oilspill Separation System performed very well with respect to both water removal and hydrocarbon removal at influent crude oil ratios below about 50%. The system was not negatively impacted by the presence of mousse in the influent. The system performed better against influent emulsions than with crude oil, even when influent mousse ratios exceeded 50%. The separator was able to handle influents of either 100% water or 100% oil or mousse quite effectively, and was the only separator tested that demonstrated this capability. In addition, the system has a relatively low weight and weight to capacity ratio despite its large footprint.

The weaknesses of the system were the poor water quality results obtained when the crude oil influent ratio exceeded about 50%, a time-limited capability to handle debris (43 minutes of testing), and a tendency to increase the emulsified water content for the crude oil and water influents - sometimes showing a tenfold increase in emulsified water content. The system also showed reduced water removal capabilities when the influent was fed to the system at 50% capacity.

Intr-Septor 250: The primary strength of the Intr-Septor 250 is the low weight and low weight to capacity ratio. Its ability to handle debris without any significant impact to performance or operation for a full 45 minute period also is a significant strength. Although the separator was not able to produce extremely clean water during any of the tests, oil content consistently dropped to 1% to 7% in the water effluent regardless of influent oil ratios in all tests except the Mousse Test. The separator performed best during the Mousse Plus Emulsion Breaker Test

The primary weaknesses of the system are its inability to produce extremely clean water, relatively poor water removal efficiency, and poor reliability. Hydrocarbon removal was most affected during the Mousse Test, where the water effluent stream still contained approximately one half the fraction of the influent, independent of the influent ratio.

Conclusions and Recommendations: None of the separators evaluated in this program met all target requirements for the oil/water separator component of a vessel of opportunity oil recovery system for the Coast Guard or MSRC. Additional technology development and system optimization is recommended to produce a mature technology capable of meeting offshore spill response requirements for easily transportable oil/water separators.

Each of the manufacturers of the three mechanical separators tested in this program recommended system modifications based on the test results for their separator. These are included in the main body of the report. Some additional

modifications are recommended for each system, and are included at the conclusion of the report, as are recommendations for additional testing of upgraded separators. Because of apparent design limitations of the surge tank tested, no quantitative determination of the value of adding a first stage surge tank to any of the other mechanical systems could be made. However, the effect of the first stage surge tank integral to the Vortoil system was an important factor in the favorable results obtained with that system. Additional consideration to including a first stage tank with other mechanical separation systems is warranted.

Advancements in separator technology should continue to be pursued. Tests of any new or upgraded systems should be compatible with the tests documented in this report to enable the compilation of a database of comparable test results for different separator technologies and systems.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

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The author and sponsors of this work wish to thank the Amoco Oil Company and its Yorktown Refinery for their cooperation and assistance in hosting the tests documented in this report, and the Naval Sea Systems Command Supervisor of Salvage for providing the majority of the mechanical and support equipment used at the test site.

1.0 INTRODUCTION

This report documents the evaluation of four oil/water separators, conducted by the Naval Civil Engineering Laboratory (NCEL, now the Naval Facilities Engineering Service Center, or NFESC) for a project jointly sponsored by the U.S. Coast Guard Research and Development Center (USCG R&D Center) and the Marine Spill Response Corporation (MSRC). The tests were conducted from October to December 1992 on the grounds of the Amoco Oil refinery in Yorktown, Va. NCEL conducted the test operations with support from Amoco, U.S. Naval Sea Systems Command Supervisor of Salvage (NAVSEA SUPSALV), Global Phillips Cartner (GPC), PCCI, Miljø & Ånlegg, and Environmental Testing Services, Inc. The objective of the oil/water separator test and evaluation program was to evaluate the performance of each separator under a variety of test conditions that replicated points in the spectrum of operating conditions expected during an offshore oil spill recovery operation by the USCG or MSRC. These conditions include a range of oil/water ratios, different oil types, viscosities and densities, including water-in-oil emulsions or, "mousse", different flow rates (as a percentage of separator capacity), different oil viscosities and densities, influent containing debris, the use of a chemical emulsion breaker, and operation subjected to the ship motions expected at sea.

2.0 BACKGROUND

Both the Coast Guard and MSRC are developing oil recovery systems that can be transported to the vicinity of an offshore oil spill and used on a vessel of opportunity available near the spill site. These systems include weir-type skimmers for retrieving the oil, and temporary storage devices (TSD's) for storing the recovered product offshore. Weir-type skimmers can typically collect as much as 85% water, which takes up valuable space in the temporary storage devices, requiring frequent trips back to shore for off-loading. Oil/water separators could improve the efficiency of recovery operations by significantly reducing the amount of recovered water that would need to be stored offshore, allowing recovery crews to stay on site longer. An oil/water separator could be used directly in between the skimmer and the TSD to prevent unnecessary water storage, or could be used to clean water decanted from the TSD at the site of the spill. However, in order to discharge the water effluent stream from the separator, the separator must be able to produce a water effluent clean enough to meet environmental regulations. The current EPA regulation for water discharge limits petroleum in water discharges to 15 ppm. While this regulation was developed to apply to produced water for long-term applications (offshore oil platforms, for example), it is the only existing regulation regarding hydrocarbon content for effluent water streams related to oil recovery operations. Since the purpose of using a separator is to reduce the amount of water requiring storage offshore, the water effluent discharge from the separator must be clean enough to meet environmental regulations for discharge at the site. The ability to effectively remove excess water

while producing a clean water effluent is the most important criteria for separator evaluation.

The logistics requirements of a fly-away system require that any separator included be compact and lightweight to allow easy air transport, movement at the vessel mobilization site with commonly available handling equipment such as forklifts, and to conserve deck space on the vessel of opportunity. The original target specifications for an oil/water separator included weight between 4,000 and 6,000 pounds and a logistics volume of 125 ft^3 maximum. In addition, the oil/water separator for these applications should be easy to operate and maintain, should not require a dedicated operator, have power requirements that are easily met with vessels of opportunity, and be capable of processing 250 gpm of influent to match the skimmer capacity of the weir skimmers.

Three mechanical oil/water separators were selected for testing based on their capacity, weight and size, claimed separation ability, and the technology used to effect the separation. The separators selected for testing were the Alfa-Laval OFPX 413 disk-stack centrifuge system, Conoco Specialty Product's Vortoil Oilspill Separation System, incorporating a first stage surge tank and 2 stages of hydrocyclones, and International Separation Technology's Intr-Septor 250 centrifugal separator. In addition, a surge tank was included in the test program to obtain data on water effluent quality from a simple tank system to determine the value of including a surge as a first stage in a hybrid system with any of the other more sophisticated systems tested.

The tests documented in this report represent the first phase of the OWS RDT&E effort for the USCG and MSRC. Future work may include further development and testing of systems tested in this program that showed promise during the tests, tests of other separator systems, or the development of new or hybrid separator systems specifically designed to meet operational requirements.

3.0 SEPARATOR SELECTION

In 1991, the USCG R&D Center tasked MAR Incorporated to conduct a market survey of oil/water separators to identify candidate systems to be included in this test program. The final report for this effort was completed in January 1992[1]. In addition, the USCG R&D Center placed advertisements in the Commerce Business Daily (CBD) and trade publications that dealt with oil spill response, soliciting information from oil/water separator manufacturers who produce separator systems that were appropriate for inclusion in the RDT&E program.

The information in the MAR report and responses from the advertisements were compiled and then reviewed by the "OWS Working Group" - a team consisting of personnel from the USCG R&D Center, USCG Headquarters, USCG National Strike Force, MSRC, NCEL, and Scientific and Environmental Associates, Inc. (SEA). Promising separator systems were identified based on their capacity, size, weight and other logistics characteristics, claimed separation effectiveness and effluent water

hydrocarbon content, and the technology used to produce the separation. The manufacturers of the separator systems chosen during the first round of selection were invited to give presentations on their separator systems to the OWS Working Group, which provided the opportunity to obtain additional technical information on the systems, and answers to specific technical or operational questions on each separator. After the presentations were completed, the OWS Working Group again evaluated the information and decided upon several separators to be included in the test program. Each of these manufacturers were invited to participate in the test program by providing the use of their separator and technical personnel sufficient to run the device, in exchange for the data resulting from the test program. Two manufacturers invited to participate declined as they were at that time unable to provide systems for the test program scheduled for Fall 1992.

Four separators were selected for the test program, three mechanical separators and one gravity separators modified for the tests. The three mechanical separators included in the test program were the Alfa-Laval OFPX 413 disc-stack centrifuge, Conoco Specialty Products' Vortoil Oilspill Separation System, and International Separation Technology's Intr-Septor 250. Both the Vortoil and Intr-Septor systems were prototypes that had not been tested with oil prior to the tests documented in this report, and the Alfa-Laval unit was deigned for other oil separation applications. At the time of selection, no oil/water separator designed specifically for the separation of recovered oil was readily available on the market.

In addition to the three mechanical separators, a surge tank was included in the test program. This was added in order to quantify the properties of the water effluent from a surge tank, which in turn could be used to determine the benefit of including a surge tank as a first stage in a separator system with one of the three more sophisticated separators as the second stage. It was believed that a first stage surge tank would allow removal of large debris, highly viscous emulsions, and already separated oil, providing more favorable influent conditions for the second stage mechanical separator. In addition, a surge tank could provide a favorable environment for the addition of emulsion breaking chemicals, giving the chemicals time to take effect before mechanical separation. Desirable characteristics for the surge tank were a 250 gpm capacity with four minutes of residence time, or 1000 gallon volume. No tests were conducted on an actual combined system incorporating the surge tank, and the evaluation of any improvement gained by incorporating this system was to be performed using the data gathered from the separate tests. Results from the surge tank tests, which are discussed in more detail later in the report, did not produce any significant change in water quality from influent to water effluent; however, this is believed to be due more to design characteristics of the surge tank and that much better results would be produced with some simple design modifications. Because there was no significant difference between influent and water effluent quality for the surge tank tests, no analysis of a combined system is presented in this report.

Detailed descriptions of each separator system and the associated principles of operation are included later in this report, immediately preceding the discussion of test results for each particular system.

4.0 TEST PLAN DEVELOPMENT AND DESCRIPTION

MAR Incorporated was tasked to develop a baseline test plan[2] for the separator test and evaluations. This baseline plan incorporated test plans and procedures from ASTM F 933-85 "Standard Guide for Evaluation of Oil/Water Separator Systems for Spilled Oil Recovery Applications"[3]. The OWS Working Group reviewed the baseline test plan, and where appropriate, modified the test parameters to better represent the actual operating conditions expected by the USCG and MSRC.

Detailed test plans were developed by NCEL, based on the MAR plans and reflecting the modifications recommended by the OWS Working Group. Five test series, each simulating different operating conditions expected at an offshore oil spill recovery site, were included in the plans for each separator. Each test series consisted of several 10 minute tests with slightly different influent characteristics. Each test series was based on the same basic test plan, with only the petroleum product, state of motion, or chemical additives used, changing from series to series. By varying only one variable per series and test, the impact to performance from that condition could be isolated. The initial test of each series was conducted with a 100% water influent so that any background contamination of the water effluent stream due to residual oil in the test facility lines could quantified.

In addition to the five performance test series, the weight and size of each separator system was determined, and an informal assessment of operability, maintenance requirements, reliability, transportability, and safety considerations was performed by noting requirements or deficiencies throughout the program.

Brief descriptions of the five test series are presented below. The test plan matrices for these are included in Appendix A.

4.1 Crude Oil Test Series. The Crude Oil Test Series evaluates separator performance at influent oil ratios of 0%, 5%, 25%, 50% and 100% oil, at full capacity, for 10 minutes each. In addition, two other 10 minute tests with 5% influent oil, at 50% and 25% separator capacity are included. The purpose of this test series is to determine the basic performance of the separator under various influent oil ratios using a crude oil, and to determine the impact that reduced capacity may have on separator performance.

4.2 Sea Motion Test Series. The Sea Motion Test Series replicates the full capacity tests of the Crude Oil Test Series, using the same oil and influent oil ratios, but with the added condition of simulated sea motion conditions. The Sea Motion Test Series was performed with the amplitude of motion set at $\pm$ 15° from the horizontal plane (or 30° total amplitude), and at a period of approximately seven seconds. The purpose of these tests is to determine the impact that simulated sea motion has on separator performance at different influent oil/water ratios.

4.3 Mousse Test Series. Like the previous test series, the Mousse Test Series replicates the full capacity tests of the Crude Oil Test Series, but with a water-in-oil

emulsion, or "mousse", substituted for the crude oil. The purpose of these tests is to quantify the impact of a viscous emulsion on separator operation and performance at different influent mousse and free water ratios.

4.4 Mousse With Emulsion Breaker Test Series. This series of tests replicates the Mousse Test Series with a chemical emulsion breaker added to the influent. In this test series, Exxon's Breaxit 7877 was added at a target rate of 600 ppm of total flow for each test in the series. The purpose of these tests is to determine the positive or negative impacts to separator performance due to the addition of a chemical emulsion breaker over the same range of influent mousse ratios tested in the Mousse Test Series.

4.5 Debris Test Series. The Debris Test Series differs in format from the other tests described, in that it consists of only two tests. The first test, as in all the other test series, is 100% water at full capacity to establish a baseline for the water effluent quality. The second test is conducted at full capacity, with a target influent oil ratio of 25% (using the same oil as that for the Crude Oil Test Series), with the following debris mixture added at a rate of 0.1 pounds per minute per 100 gpm of separator capacity for 45 minutes:

1/4 inch wood chips	10% by weight
#10 mesh size sawdust	10% by weight
#40 mesh size sawdust	40% by weight
#140 mesh size sawdust	40% by weight

The total amount of debris added to the influent was in accordance with the ASTM F-933 guidelines. The breakdown of particle sizes and weights was recommended in the MAR baseline test plan, with the exception of the finest material, for which the MAR plan recommended a #200 mesh size. The #140 mesh size material was substituted only because it was more readily available. The ASTM guidelines recommended the use of vegetable fibers simulating chopped seaweed or hay. Sawdust was selected as a readily available vegetable material that could be obtained in graded sizes.

4.6 Test Plan Modifications. Due to time limitations, the surge tank was tested only under the conditions of the Crude Oil and the Sea Motion Test Series. In addition, after the Alfa-Laval system and surge tank were tested, the Crude Oil and Sea Motion Test Series were combined into a single test series, adding one ten minute simulated sea motion test to the Crude Oil Test Series, and deleting the 25% capacity test. This provided results on the impact of both reduced capacity and sea motion, while saving the time required to complete both complete test series separately. The test matrix for this modified Crude Oil Test Series also is included in Appendix A.

5.0 TEST FACILITY

The tests were conducted on the grounds of the Amoco oil refinery in Yorktown, Virginia, on a concrete pad used for cleaning heat exchangers. The cleaning pad is gently sloped to move all fluids towards an oil sewer drain located at the base of the pad. The oil sent to the sewer is separated from disposed water, treated, and reclaimed at the refinery's oil sewer reclamation facility. Brackish water from the nearby York River supplied the refinery's fire main lines, and was available near the test site for influent water supplies. A schematic and a photograph of the test facility are shown in Figures 1 and 2, respectively. For more detailed information than that included below, a more thorough description of the test facility and equipment used for the tests can be found in reference 5.

5.1 Oil and Water Storage. The water supply, water effluent and debris/mixing tanks were all modular tanks erected at the site by GPC personnel. Salt was added to the water supply tank to increase the salinity of the York River water from about 19 parts per thousand (ppt) to a target of 35 ppt to match typical ocean water salinity. Six ISO-compatible horizontal tanks were leased from Eurotainer for petroleum supply storage, effluent oil or mousse, and diesel storage tanks. Diesel was used only as fuel for the generators at the site and for thinning waste oil and mousse before discharge into the Amoco oil sewer. The primary reclaimed oil/mousse tank, which received the oil and mousse effluent from the separators, was mounted on a set of portable truck scale load cells. This provided data on the change in weight of the contents of the tank during each test, providing back-up information for verifying oil/mousse effluent rates. Due to problems with the flow meters, this data became the primary means for determining oil/mousse effluent flow rate.

5.2 Piping and Instrument Stations. Flexible and semi-rigid hose, provided by NAVSEA, was used throughout the test set-up. NAVSEA also provided Desmi DOP 250 Archimedean screw pumps, and Marco submersible hydraulic pumps for use during the tests. Seven instrument stations, consisting of 7 foot sections of 4 inch diameter pipe were specially designed and fabricated by PCCI for the tests. Each of the instrument stations was configured with ports for flow meters, temperature probes, pressure sensors, sampling ports, and air vents to bleed off any air trapped in the pipe. Two of the instrument stations also included plexiglass viewing ports for observing fluid flow. These were located in the instrument stations for the influent and water effluent lines. All instrument stations were elevated at an angle of approximately 45° to 60° to ensure full pipe flow at the flow meter and sampling port locations.

5.3 Flow Meters. Three types of flow meters were used in the test set-up. A Signet Metalex Model P525-2 paddle-wheel flow meter was used for the water influent line, six Alphasonics 6500 immersion ultrasonic flow meters were used to monitor oil/mousse influent, mixture influent and effluent streams, and a Dynasonics M3-902

strap-on ultrasonic flow meter was used as a "mobile" back-up meter, used to provide redundant flow data at critical locations.

5.4 Other Instrumentation. All electronic sensors, including flow meters, pressure and temperature sensors, and the load cells under the primary reclaimed oil/mousse tank, were hard-wired to a central data acquisition system computer located in the command trailer. All data was logged every two seconds using a Campbell data logger, and then stored in the computer. The computer software used to monitor and store the data also provided a real-time graphic display of all incoming data. This screen was monitored at all times during the tests.

5.5 Sea Motion Simulation Table. The oil/water separator being tested was placed on a special "swing table", designed and fabricated by PCCI especially for this program. This table produced the simulated sea motion for the sea motion portions of the test program. The swing table could be locked in place, allowing all tests to be conducted with the separator mounted on the table. Details regarding table operation and test procedure are included later in this report.

5.6 Influent Mixing Equipment. To ensure thorough mixing of the oil or mousse and free water, particularly at low flow rates, a recirculating loop of four inch hose, with a centrifugal pump placed within the loop, was included in the test set-up. The flow inside the loop was kept at approximately 400 gpm, ensuring turbulent flow, and preventing premature separation of the oil/mousse and water before the stream reached the separator. Using this set-up for all tests ensured that all separators were tested with comparably mixed influents, independent of actual separator flow capacity.

5.7 Back Pressure Prevention. To prevent unacceptable back pressures for three of the separators, the oil/mousse and water effluent streams were captured in open intermediary tanks and then pumped into the reclaimed oil/mousse or water effluent tanks. Two 400 gallon plastic tanks were fitted with four inch fittings near the bottom of the tank for this purpose.

5.8 Support Facilities. Temporary support facilities at the test site included four vans located at the site, all provided by NAVSEA SUPSALV for the duration of the tests. Two 20 foot vans were pre-configured as a rigging van and shop van, and one 40 foot trailer as a command center for spill response operations. The command van housed the central data acquisition computer system for electronic data, as well as communications and office equipment, and provided space for planning meetings and data reduction. The fourth NAVSEA van, originally configured as a bunk van, was re-configured at the site by Amoco personnel to serve as an on-site remote chemical analysis laboratory.

5.9 On-Site Laboratory Facilities. The on-site laboratory van was outfitted with the following primary analysis equipment: A Metrohm Karl Fischer titrator, Bohlin Visco 88 viscometer, Malvern Mastersizer-X droplet size analyzer, Anton-Paar hand-held density meter, Davis Instrument water analyzer, Baroid filter press (for removing solids samples taken during the Debris Test Series), and a Horiba spectrophotometer oil analyzer for field approximations of total petroleum hydrocarbons in water samples. Ancillary equipment for the facility included balances, computers, and glassware. On-site chemical analysis support was provided by ETS, and was overseen by Miljø & Anlegg. The selection of the bulk of the analysis equipment purchased for on-site use was based on equipment included in a field portable oil analytical kit recently developed by Environment Canada[4].

6.0 PETROLEUM PRODUCTS

Three different product types were originally specified in the detailed test plans. The target properties for these products are shown in Table 1, alongside the actual typical properties of the products used during the tests. The target properties were selected by the OWS Working Group to represent the range of conditions that might be encountered at a marine oil spill over time.

6.1 Crude Oil. The crude oil available from the Amoco refinery was Venezuelan crude BCF-17, with viscosity typically ranging between 500 and 1300 cP at 16° C when measured at a shear rate of 10 sec^{-1}. Specific gravity averaged about 0.92. This oil was used in the Crude Oil, Sea Motion and Debris Test Series. A great deal of the variation in viscosity seen during the tests is attributed to the refinery's practice of periodically thinning the crude oil in the refinery's storage tank when the level dropped near the bottom. This was done to facilitate removal of the product. Because of the thinning, some of the tests were conducted with a lighter product having a much lower viscosity - sometimes below 100 cP at shear rate 10 sec^{-1}. In particular, all of the tests on the Alfa-Laval, the first few crude oil tests on the surge tank, and the Debris Test Series on the Intr-Septor were conducted with much lighter oil than the other tests.

6.2 Mousse. The water-in-oil emulsion, or mousse, was made using the Venezuelan crude and salt water. The oil storage tank labeled Tank #1 in Figure 1 was dedicated to mousse production and storage during the test program. Oil was pumped out of the tank through a loop of six inch hose, to which salt water was injected before the loop returned the mixture to the storage tank. Total flow rate in the loop was approximately 440 gpm. Samples were periodically collected and analyzed for emulsified water content and viscosity, and the water injection rate was adjusted based on the results of the analysis. Mousse viscosity averaged about 20,000 cP at shear rate = 10 sec^{-1} and an average temperature of 18° C, although viscosities as high as 35,900 cP (at shear rate = 10 sec^{-1}, 18° C) were obtained near the end of

the test program when ambient temperatures had dropped to 4° to 5° C range, and more proficiency at mousse production had been gained over the course of the tests. Emulsified water volume was typically between 55% and 70%. Specific gravity of the mousse varied from about 0.93 to 0.98. Mousse made with the thinned crude oil had comparable volumes of entrained water, but viscosity only reached 3500 to 4500 cP at shear rate = 10 sec^{-1}, 21° C. It took roughly six to eight hours to make 5000 gallons of mousse. Because the production time for the mousse was so long, every effort was made to recycle the emulsion in between tests that required mousse. This was quite effective and saved a great deal of test preparation time. After recycling, samples were collected and analyzed for emulsified water content and viscosity. Usually only one or two hours of recirculation and water injection was required to reconstitute the mousse to its original consistency. No mousse was recycled from tests that included the addition of emulsion breaker.

7.0 TEST PROCEDURES

7.1 Preparation and Timing. At the start of each test series, 100% water was fed through the system at full separator capacity while the separator under test was started. All timepieces were synchronized with the central data acquisition system computer, as all data was to be correlated by time for later analysis. The beginning and end of each test was announced to all test personnel via walkie-talkie and hand signals.

7.2 Influent Ratio Establishment. For tests where the influent consisted of an oil or mousse and free water mixture, preparation included adjusting flow rates to match the target ratio. The target ratio, ± 5%, was achieved by collecting 100 ml samples at the influent sampling station immediately upstream of the separator, and adjusting flow rates based on a visual analysis of the sample in a graduated cylinder. The separator under test was already processing the influent at this time, but the test did not officially begin until the proper oil or mousse to water ratio had been reached. Obtaining the proper ratio took about ten minutes on average.

Due to problems with monitoring, and hence control, of influent flow rates, coupled with errors in the visual estimates of influent oil/mousse content from the graduated cylinders, later data analysis indicated that many tests were conducted with influent mixtures far from the target conditions. Each such occurrence is noted in the discussion of tests results presented later in this paper. The next major section of this report discusses data analysis and accuracy in more detail. A more thorough discussion of the cause of the errors and recommendations for improvements to test equipment and procedures is provided in reference 5.

7.3 Data Collection. Temperature, pressure, effluent oil/mousse tank weight, and flow rate data were collected electronically every two seconds and stored in the central data acquisition computer system in the command trailer. The fluid level in the

water effluent tank was measured with a measuring tape at the beginning and end of each test, for verification of flow rate. Similarly, the weight of the oil/mousse effluent tank was monitored during each test to provide oil/mousse effluent flow rate data. Because of difficulties with the flow meters, these measurements provided the primary oil/mousse and water effluent flow rate data used in the analyses.

7.4 Fluid Sample Collection. During each test, 100 ml samples were taken each minute in graduated cylinders at the influent and both effluent stream sampling ports. The oil or mousse to free water ratio was determined visually and logged. The samples were left for approximately five minutes before they were disposed of, in order for the sampling technicians to verify the oil or mousse to free water ratio after five minutes of settling time. These samples provided the primary oil or mousse to free water ratio data for the influent and both effluent streams.

In addition to the one minute samples, every five minutes a one liter sample was collected at each influent and effluent stream sampling location. These samples were collected in separatory funnels and allowed to settle briefly before each sample was separated into two sample bottles, one containing the oil/mousse portion and the other the free water portion. These were then taken to the on-site lab facility for immediate analysis. One liter samples from the influent oil or mousse product and influent water supply lines were collected at this time as well. The volume of all separated samples taken to the on-site lab facility was compared visually to a calibrated volumetric scale to estimate the percentage of oil/mousse and free water in each original sample.

7.5 On-Site Laboratory Analysis

7.5.1 Oil and Mousse Portions of Laboratory Samples. For the oil/mousse samples, the on-site laboratory analysis consisted of the following additional procedures to document the physical properties of the oil/mousse portions of the influent and effluents.

1. Simultaneous determination of viscosity and temperature, recording the viscosity value at shear rate closest to 10 sec^{-1}. Viscosity was measured over a range of shear rates, typically between 2 and 20 sec^{-1}.

2. Determination of relative density by comparing weights of equal volumes of the oil/mousse sample and distilled water. (During the test program the on-site chemists found it difficult to use the hand-held density meter purchased for the test program, due to the high viscosity of the oil/mousse fluids. Environment Canada, having previous experience with the device, developed alternate techniques for using the meter with viscous fluids, including very viscous emulsions. The methods for using this meter with viscous fluids is documented in reference C).

3. Determination of the emulsified water volume in the oil/mousse sample, using the Karl Fischer titrator.

7.5.2 Free Water Portions of Laboratory Samples. The on-site analysis for the free water samples consisted of the following tests to document the properties of the free water portions of the influent and effluents:

1. Determination of relative density using the hand-held Anton-Paar density meter.

2. pH measurement.

3. Temperature measurement.

4. Salinity determination.

5. Mean droplet size analysis. Background samples for the droplet size analysis were run at least twice each day, using samples taken from the main water supply tank in order to match salinity with the samples to be collected that day.

6. Determination of the total petroleum hydrocarbons (TPH), using the Horiba field spectrophotometer. The field spectrophotometer was calibrated to a single point calibration at 200 ppm.

7.6 Off-Site Laboratory Analysis. In addition to the on-site laboratory analysis, selected samples were taken daily to the ETS laboratory in Norfolk, Virginia for further analyses that could not easily be performed at the test site. Analyses conducted at the ETS facility included additional Infra-red Spectrophotometry Total Petroleum Hydrocarbon analysis (EPA Method 418.1) as a double check on the field unit data collected at the site, Interfacial Tension of Oil against Water - Ring Method (ASTM D971-91) to document the properties of the crude oil used in these tests, Water Separability of Petroleum Oils and Synthetic Fuels (ASTM D 1401-91), also to document the properties of the crude oil used in the tests, and Insoluble Contamination of Hydraulic Fluids by Gravimetric Analysis (ASTM F313-78) for samples from the Debris Test Series to document the amount of debris contained in the oil portions of fluid samples. The purpose of documenting crude oil properties with the interfacial tension and water separability tests was to facilitate comparison of these tests results with those from other tests where a different oil was used.

7.7 Special Test Procedures. In addition to those test procedures described above, special procedures were required for the Sea Motion Test, Debris Test and Mousse with Emulsion Breaker Test Series.

7.7.1 Sea Motion Test Series. For the Sea Motion Test Series and sea motion tests of the modified Crude Oil Test Series, the separator being tested was started, the influent mixture was adjusted, and the swing table set in motion. The amplitude of motion was mechanically pre-set at ± 15° from horizontal, and the period of motion was adjusted hydraulically to reach the target period of approximately seven seconds. This normally took less than five minutes. After the motion was steady, the test series were started. Each separator was positioned on the swing table with its center of gravity located approximately five feet from the center of rotation, and oriented such that the direction of motion would have the greatest likelihood of impacting performance. Some separators were supported on dunnage to achieve the five foot distance between the center of gravity and the swing table's center of motion.

7.7.2 Debris Test Series. During the Debris Test Series, some or all of the influent water (depending on separator capacity), was taken from the debris/mixing tank shown in Figure 1. A hose was connected to the suction end of the pump in the tank, with the suction end of the hose suspended a few inches below the water surface in the tank. This created a slight vortex when the pump was operating. The debris was mixed with a small amount of crude oil, and this slurry was steadily poured into the vortex over the duration of the test to entrain the debris in the influent stream.

7.7.3 Mousse with Emulsion Breaker Test Series. For the Mousse with Emulsion Breaker Test Series, Exxon Breaxit 7877 was added at a rate of approximately 600 parts per million of total flow on the suction side of the centrifugal pump in the recirculating loop using a small peristaltic pump. The dosage rate was determined during laboratory experiments conducted with the mousse made at the site. The emulsion breaker was injected immediately before the start of each test, but after the proper influent mousse/water ratio had been achieved. For the tests on the larger capacity separators (250 gpm), the emulsion breaker had to be thinned down with one part mineral spirits to three parts Breaxit 7877 to facilitate injection into the line. The peristaltic pump available for the tests was unable to overcome the combination of higher line pressures induced during the tests and higher injection rate requirements. On-site tests with Breaxit 7877 thinned with mineral spirits indicated no change in performance properties when compared to the unmodified emulsion breaker. The emulsion breaker or emulsion breaker mixture was drawn from a bucket or large graduated beaker, depending on the total volume required during the tests. The starting and ending fluid levels for each test were recorded to verify the total volume of chemical used for each test.

8.0 DATA ANALYSIS AND ACCURACY

8.1 Flow Rate Calculation. The first step of data reduction and analysis after the tests were completed was computation of the actual flow rates. For each test, the oil/mousse effluent flow rate was calculated by dividing the total difference in weight

in the oil/mousse effluent tank by the unit weight of the oil/mousse effluent, (itself calculated using the laboratory density data), to determine the total volume of oil/mousse effluent. This in turn was divided by the actual time recorded for the test. Water effluent rate was calculated by determining the total change in volume in the effluent water tank, and dividing this by the total time for the test. These numbers were added to determine the total influent flow rate.

8.2 Influent and Effluent Oil or Mousse to Free Water Ratio Determination. Determination of the influent and effluent oil or mousse to free water ratios was more complicated. The one minute graduated cylinder data for each test (nine samples per sampling station per test) were averaged over each test, as were the proportions of oil/mousse and water in the laboratory samples (two samples per sampling station per test). A mass balance analysis was conducted using only the oil/mousse and water effluent stream graduated cylinder data, and incorporating the emulsified water volume data from the laboratory samples corresponding to the test, to back-calculate the influent oil or mousse to free water ratio. The specific test conditions and events during the day of the test also were reviewed to identified any particular situation that may have impacted data quality that day.

If the mass balance analysis using the effluent graduated cylinder sample data matched well with the influent sample station graduated cylinder data, and the laboratory samples did not show conflicting results, the graduated cylinder data was used for the remainder of the analysis of the test results. When there were discrepancies between the data sets, all data was reevaluated, and the data to use for analysis was chosen based on the relative reliability of the data for that test, taking into account any special circumstances noted during the operation. In the few circumstances where selection of the most reliable data was not straightforward, the benefit of the doubt was given to separator performance, and the most favorable data was used for the remainder of the analysis in that test. For the data shown in the remainder of this report, when oil/mousse content data taken from sources other than the graduated cylinder samples is used, the origin of that data is noted.

8.3 Potential Sources of Error in Oil or Mousse to Free Water Ratio Determination

8.3.1 Adhesion of Oil/Mousse to Sample Containers. In general, there were several factors that could contribute to error in reading the graduated cylinder samples. Although the cylinders had been treated with silane to help prevent the oil/mousse from sticking to the glass, there was enough adhesion of oil/mousse to the glass to increase the difficulty of determining the oil or mousse to free water ratio. Unseen pockets of water trapped inside the oil/mousse also may have been responsible for higher oil/mousse content readings in some samples.

8.3.2 Human Errors. Human errors also must be considered. Errors of one to two percent in free oil or mousse to free water contents in some samples can be attributed to error in visual estimations, especially when the cylinders were filled over or below

the 100 ml mark. Significant over or under-sampling was rarely observed during the tests, however, and the magnitude of the error, already small, would be reduced when averaged with the other samples taken during the test. For the influent graduated cylinder samples, the sampling technician knew what the target oil or mousse content was, and knowing the desirable result may have influenced the process of estimating oil/mousse content. This is especially important for this sampling station, where the highly mixed influent was the hardest to "read".

The water effluent stream graduated cylinder data were taken to be the most reliable data, followed by the effluent oil/mousse stream graduated cylinder data. During mechanical separation, the oil droplets grow larger, producing better and faster separation in the graduated cylinder samples taken from the influent stream, making them easier to read[6]. In addition, nine samples were collected during each test at all graduated cylinder sampling stations, effectively removing the impact of arbitrary errors and non-representative samples.

8.3.3 Errors in Oil or Mousse to Free Water Ratio Estimations for Laboratory Samples. The laboratory sample data on relative volumes of oil/mousse and free water for each one liter sample were considered to be less reliable than the graduated cylinder sample data. This is because the percentages were estimated only to the nearest decade of percent (i.e., 10%, 20%, etc.), and only two samples were taken for each test. In addition, oil or mousse often stuck to the inside of the separatory funnels and was therefore not included in the laboratory estimation of oil/mousse and free water ratios. As a result of these two factors, most laboratory samples for the water effluent line that contained from one to three percent oil or mousse, as determined from nine graduated cylinder samples, were recorded as 100% free water. It must be noted that the task of estimating the relative volumes of oil/mousse and free water in the lab samples was added to the laboratory analysis after a few tests had been run, and the difficulty in determining oil/mousse to water ratios from the influent sampling station has been observed. The laboratory estimation was intended only to provide back-up data points for oil/mousse and free water ratios of the samples. For future tests, small, portable centrifuges are recommended for more accurately determining actual oil/mousse to water ratios at the sampling stations.

8.3.4 Unstable Emulsions. Another possible source of error in determining the oil/mousse to water ratios is the possibility of unstable emulsions being created during separation[6]. The test results show that two of the separators produced significant increases in the total emulsified water volume of the test fluid. This was documented by comparing the total emulsified water volume in the influent to that in the combined effluent stream, which was calculated using the laboratory titration results. The titration was completed within five minutes of the sample being taken, but this length of time may have been sufficient for an unstable emulsion produced by the separator to separate. If this was indeed occurring, the graduated cylinder readings at the effluent stream sampling stations would show a higher percentage of oil or mousse, as its volume was increased by emulsification. This would not be reflected in the

laboratory samples because the emulsion had already broken down by the time the one liter sample had been separated into the two laboratory containers.

8.3.5 Laboratory Equipment Accuracy. Also noted during the test program were arbitrary errors of $\pm$ 10% in emulsified water volume when determining the emulsified water content of the produced emulsions with the titrator[6]. Because this error is not dependent on the source of the sample, however, the error should be the same on the influent and effluent sample analyses over the course of the tests. This means that repeated patterns of increased or decreased emulsification are most likely not attributable to systematic inaccuracies in chemical analysis and are linked to the separation process.

8.4 Off-Site Analysis. The off-site analyses conducted on laboratory samples included Total Petroleum Hydrocarbon (TPH) analysis, the determination of solids in the influent and effluent streams taken during the Debris Test Series, the determination of interfacial tension, and determination of the separability of water from oil.

8.4.1 Total Petroleum Hydrocarbon (TPH) Analysis. The Total Petroleum Hydrocarbon (TPH) analysis conducted off-site on some samples was performed to spot-check the results of the field spectrophotometry performed at the site. In instances where the results did not match between the two analyses on the same sample, the lower reading was used in analysis, again giving the benefit of the doubt to separator performance. It should be noted that neither method of determining the oil content in water is precise, and both methods produce only estimates of actual oil content[7].

8.4.2 Solids Content of Oil Samples. The solids content determination was included in the test plans to determine how the total influent debris content was divided between the two effluent streams. The results from the solids content in samples taken during the Debris Test Series, as they showed higher concentrations of solids in samples taken from the influent oil stream, which contained no debris, than in the influent or effluent lines after debris had been added. The reason for these inappropriate readings has not yet been determined.

8.4.3 Interfacial Tension and Separability of Water from Oil. The results from the interfacial tension test (ASTM D971-91) and separability of oil from water (ASTM 1401-91) were included in the test program primarily as a means for documenting the characteristics of the oil used for the test program. This was done so that the results from this program could be compared to those from other future test programs with enough information on oil and influent properties to make the comparison meaningful. In addition, this data also could be used to document changes in oil characteristics between separator tests included in this program, providing more insight into the reasons for differences in separator performance. Influent oil stream samples were used for these tests. The separability test was incorrectly performed, with only four

of eighteen sample analyzed correctly. Therefore, the results of these tests are not discussed in this report.

8.5 Treatment of Irregular Data in Analysis. For all data collected during the tests and from all sources, any data points that were extremely abnormal or unexpected that could not be explained by events recorded during the test were eliminated from averaging, where appropriate, or were not used in further analysis. In the rare instances where abnormal or unexpected data was included in the analysis of test results, the instance is noted in the data tables and discussed in the text.

9.0 PRESENTATION OF RESULTS

The remainder of this report concentrates on the test results from this program. Each of the next four major sections of the paper focuses on one of the separator systems tested. The sections are arranged in the same order in which the separators were tested, with the Alfa-Laval results presented first, followed by those for the surge tank, Vortoil and Intr-Septor systems. Each separator test result discussion begins with a description of the separator system and operating principles, followed by a discussion of physical and logistics characteristics. The specific test set-up used for that separator is presented next.

Individual test results are presented in the order in which the tests were conducted for each separator. For each test, any modifications to the original test plan are discussed, along with the test conditions for that test, including oil or mousse characteristics and other special test parameters. Following this information is a discussion of the mass balance analysis results, water removal and hydrocarbon removal, change in the emulsified water content between the influent and oil/mousse effluent stream, oil droplet size across the separator, and influent and effluent line pressures.

Where appropriate, the results of each test series are compared to other test series on the same separator, to highlight differences in performance attributable to changes in influent or operating conditions. After all tests have been discussed, a general assessment of the operability, maintainability, reliability, transportability and safety of operating the separator system is presented. Each separator section concludes with a summary of the system's strengths and weaknesses, and a summary of input from the separator's manufacturer regarding performance and proposed system modifications or changes in operating conditions to improve performance. A separate section of this report includes comparisons of performance between separators, following the presentation of individual separator test results. The report concludes with recommendations for additional testing based on separator performance and manufacturers input regarding system modifications and operational adjustments to improve performance.

9.1 Definitions.

9.1.1 Water Removal Efficiency. For all tests using the non-emulsified crude oil, water removal efficiency is defined as follows:

$$\text{Water Removal Efficiency} = \frac{\text{[Free Water in Water Effluent]}}{\text{[Free Water in Influent]}} \text{ X } 100$$

For the Mousse and Mousse with Emulsion Breaker Test Series, water removal efficiency is defined as:

$$\begin{array}{l}\text{Water Removal Efficiency} \\ \text{in Mousse Test Series}\end{array} = \frac{\text{[Free Water in Water Effluent]}}{\text{[Total Free Water in Both Effluent Streams]}} \text{ X } 100$$

Defining the water removal efficiency like this for the tests containing mousse allows the amount of water broken free from emulsion, if any, to be considered in determining the water removal efficiency of the separator.

9.1.2 Hydrocarbon Removal Efficiency. For all tests, hydrocarbon removal efficiency is defined as follows:

$$\begin{array}{l}\text{Hydrocarbon} \\ \text{Removal} \\ \text{Efficiency}\end{array} = \frac{\text{[Influent Oil or Mousse Fraction \{\%\} - Effluent Water Sample Oil/Mousse Fraction \{\%\}]}}{\text{[Influent Oil or Mousse Fraction \{\%\}]}} \text{ X } 100$$

9.1.3 Differential Specific Gravity. Differential specific gravity for all tests is defined as follows:

$$\begin{array}{l}\text{Differential} \\ \text{Specific} \\ \text{Gravity}\end{array} = \begin{array}{l}\text{(Specific gravity} \\ \text{of the free water} \\ \text{portion of the} \\ \text{influent stream)}\end{array} - \begin{array}{l}\text{(Specific gravity} \\ \text{of the oil/mousse} \\ \text{portion of the} \\ \text{influent stream)}\end{array}$$

10.0 ALFA-LAVAL OFPX 413 SYSTEM CHARACTERISTICS AND TEST RESULTS

10.1 System Information

10.1.1 System Description and Principle of Operation. A photograph of the Alfa-Laval OFPX solids-ejecting disk-stack centrifuge tested in this program is shown in Figure 3. The disk-stack centrifuge couples high centripetal forces with a stack of finely spaced concentric conical disks to effect the separation of oil and water. Figure 4 is a photograph of the disk-stack being placed into the centrifuge bowl in preparation for operation. The centrifuge unit and monitoring equipment is enclosed in a container, which sits on top of a base unit that holdsthe effluent from the solids discharge line. A photograph of the centrifuge container and base unit, mounted on the swing table in preparation for a test, is shown in Figure 5.

The base unit of the system tested was modified for these tests to lower the center of gravity of the combined base unit and centrifuge unit system. Because the two units are not mechanically connected, there was concern regarding stability during the Sea Motion Test Series. The base unit height was reduced by approximately two feet for these tests. The influent is fed to the top of the bowl system with the assistance of a progressive cavity feed pump. The feed pump is shown in Figure 6.

During operation, the bowl and disk stack rotate at approximately 5000 rpm, producing centripetal forces inside the bowl in excess of 4800 g's. This force throws the water and heavier solids towards the perimeter of the bowl, while the lighter oil moves towards the center. As the oil droplets move, they eventually contact the individual disks and coalesce into larger droplets, which continue migrating towards the center of the bowl. Near the center, the droplets meet the edge of the disk stack, and move vertically to the top of the centrifuge (due to the influent pressure), until they pass through a weir at the top of the bowl and exit the system through the oil effluent line. The separated water at the outside of the bowl also flows to the top of the bowl, again under influent pressure, through a weir at the top of the bowl and out the water effluent line. An interchangeable "gravity disk" provides both of the weirs that control the effluent streams, and sets the interface between the oil and water. Different sizes of gravity disks are available to fine-tune separator performance based on the difference in densities between the two fluids being separated.

The oil and water effluent lines have pumps downstream of the centrifuge bowl, which can be manipulated to fine tune performance of the separator by changing the residence time of the two fluid phases (oil and free water) in the separator. For example, restricting the water effluent stream relative to the oil effluent provides a longer relative residence time for the water, producing cleaner water, but with the penalty of more water in the oil effluent stream.

The separator also has a solids discharge feature which can be operated manually or by automatic control. The solids are ejected through small ports in the wall of the bowl itself. The ports are opened for only milliseconds during each ejection period, but with the high centripetal forces, this is sufficient for ejecting the solids. The time is so brief that there is virtually no effect on the separation process while the solids

are being ejected. The ejected solids are collected at the perimeter of the bowl housing and exit the system through a solids discharge line. This line feeds into the base unit which holds the ejected solids. An effluent line also leads from the base unit for emptying this unit as required.

10.1.2 Dimensions, Capacity, Power Requirements and Special Logistics Characteristics. Aside from the feed pump and base unit, the system is containerized. The upper housing shown in Figure 3 contains the disk stack centrifuge, the outlet pumps, monitoring instruments, controls, tools, and a small hand powered track crane for disassembling and reassembling the bowl unit. The containerized unit sits on top of the base unit that holds the solids discharge effluent. The two units are not mechanically connected. The feed pump is separate from both the base unit and containerized centrifuge system.

System dimensions, weight, and power requirements are shown in Table 2. The manufacturer's rated capacity for the unit tested is 65 gpm. The total system weight of 16,800 includes the base and centrifuge units, the feed pump, and the weight of a 30 kW generator sufficient for providing the required operating power. The centrifuge unit alone, without controls or the containerized housing, weighs approximately 2800 pounds. The weight to capacity ratio for the total system as tested is 258 lbs/gpm.

10.2 Test Set-Up for Alfa-Laval OFPX 413. A schematic layout of the test set-up for all tests conducted on the Alfa-Laval system are shown in Figure 7. Note that the layout includes the use of a intermediate tank between the influent line and the Alfa-Laval system feed pump. Because it was too difficult to balance the flow rates between the three primary pumps used for this test (oil or mousse influent, water influent and Alfa-Laval feed pump), the influent line fed into the intermediate tank, and the feed pump drew from this tank. The intermediate tank was kept at a minimal level (only enough to prevent the feed pump from drawing air), to prevent any preliminary separation from occurring before the influent reached the Alfa-Laval system. The Alfa-Laval system was considered to start at the influent port to the feed pump.

The Alfa-Laval system was set up with a 111 mm gravity disk and was set with both effluent pumps at maximum flow. The gravity disk selected is a mid-range size, appropriate for influent conditions where the density difference is unknown, or where the density difference may change without the opportunity to substitute a more appropriate gravity disk.

In ordinary working condition, the operator would fine tune the performance by selecting the most appropriate gravity disk based on an analysis of the two fluids, and also would manipulate the effluent rates using the effluent line pumps to improve performance of the system. For the purposes of these tests, the operator was asked to select what he believed would be the most effective settings to cover all of the conditions planned during the tests, as the "ideal" oil/water separator for a vessel of opportunity recovery system would require minimal attention during operation.

10.3 Crude Oil Test Series

10.3.1 Test Plan Modifications. The original test plan for the Crude Oil Test Series included two reduced capacity tests, one at 50% and one at 25%, both with an influent oil content of 5%. These two tests were cancelled for the Alfa-Laval separator due to the relatively low flow capacity of the unit. The extremely low flow rates required to conduct the 50% and 25% capacity tests were beyond the capability of the oil supply line pump.

10.3.2 Specific Test Conditions. The target viscosity for the oil used in this test series was 1500 cP. The crude oil available for this test series was much lighter, with viscosity of the oil portion of the influent (after mixing with water) averaging about 210 cP at shear rate = 10 sec^{-1}, 18° C. The interfacial tension between a sample of oil taken from the mixed influent stream and distilled water measured 16.8 dynes/cm. No sample from the oil supply line was taken for interfacial tension determination for this particular test series.

10.3.3 Test Results. A summary of the conditions and test results for the Crude Oil Test Series on the Alfa-Laval separator system is shown in Table 3. Specific test results are discussed below.

10.3.3.1 Mass Balance Analysis. Figures 8a through 8f illustrate the fluid mass balance between influent and effluents for each test in this series. These figures show that at low influent oil ratios, the majority of the total effluent leaves the system through the water effluent line. As oil content in the influent increases, with the exception of the 100% oil test, the balance of effluent flow begins to shift more towards the oil effluent stream. The two effluent streams were nearly equal for the 37% influent oil test (test #4). These figures also indicate that the system as configured for our tests was not able to effectively handle influents of either 100% oil or 100% water, sending a considerable portion of the total flow out the "wrong" effluent line.

10.3.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 9 shows the oil content of the water effluent stream and free water content of the oil effluent stream plotted against the influent oil ratio. Figure 10 shows both water removal efficiency and hydrocarbon removal efficiency as a function of the influent oil ratio. Overall, the separator performed extremely well with regard to hydrocarbon removal, with the oil content of the water effluent lower than the background level from the 100% test for the 11% and 27% oil influent ratio tests. The system was poorer at removing water from the influent. The separator was unable to handle either 100% water influent or 100% oil influent effectively. In both tests with 100% water influent (tests #1 and #6), the separator sent 36% of the total flow out the oil effluent line. In test #5, with a 100% oil influent, 59% of the total flow (100%) went to the water effluent line. Because no data was collected at oil influent ratios between 37%

and 100%, the oil influent ratio at which hydrocarbon removal efficiency begins to drop off for this system under the specific conditions of this test cannot be determined from these test results.

Hydrocarbon removal efficiencies were 100% for all tests except the 100% oil influent test (test #5). Water removal efficiencies ranged from 63% to 83%, increasing as oil content in the influent increased.

10.3.3.3 Impact of Separation on Emulsified Water Content. Figure 11 shows the change in emulsified water content between the influent and oil effluent stream for each test of this series. Tests #2 and #5 (11% and 100% oil influent) show small reductions, and tests #3 and #4 show small increases. Overall, the changes are extremely small and do not represent any significant change in emulsified water content.

10.3.3.4 Impact of Separation on Mean Oil Droplet Size. For the oil/water influent samples, the average mean oil droplet size over all tests containing oil was 8.0 microns compared to 2.9 microns in the water effluent. The mean droplet size dropped consistently for each test in this series that used an oil/water mixture for the influent. Figure 12 shows a comparison of mean oil droplet size in the free water portion of the influent mixture, and in the water effluent stream, for each test in this series.

10.3.3.5 Influent and Effluent Line Pressure. Figure 13 shows influent and effluent line pressures for all tests in this series. Influent line pressure was generally observed to increase as the fraction of oil in the influent increased, with the exception of test #4 (37% oil influent), where influent line pressure dropped. The reason for the drop in influent line pressure is unclear, but may be due in part to the lower flow rate for this test (56 gpm), despite the increased oil content of the influent. Effluent water line pressure remained relatively steady across the entire test period, and oil effluent line pressure tended to vary with the influent line pressure, again with the exception of test #4, where oil effluent line pressure increased compared to a drop in influent line pressure. What is notable about the Alfa-Laval pressure curves is that oil effluent line pressure is greater than influent pressure, due to the effluent line pumps internal to the centrifuge system.

10.4 Sea Motion Test Series

10.4.1 Test Plan Modifications. The actual influent oil ratios for this test series exceeded the target ratios by 11% to 16% oil for test #3 through #5, due to poor ability to monitor and control influent flow rates and accurately measure oil/water ratios in real time during the test series.

10.4.2 Specific Test Conditions. The target viscosity for the oil used in this test series was 1500 cP. As in the Crude Oil Test Series, the crude oil available to us for

this test series was lighter, with viscosity of the oil in the influent stream (after mixing with water) averaging only 220 cP at shear rate = 25 sec^{-1}, 20° C, at the beginning of the test series. As the tests progressed, a steady decrease in the viscosity and density of the crude oil product was observed. It was learned later that the oil in the refinery tank from which we received our supplies would be thinned with lighter oils when the level reached near empty. At the test site, oil was pumped from the bottom of the test supply tank, drawing off the heavier fluids first, and successively lighter fluids as the test series progressed. The effect of this can be seen in both the viscosity and differences in specific gravity shown in Table 4. The interfacial tension between an oil sample collected during test #2 and distilled water measured 19.9 dynes/cm. (Note: The viscosity data presented in this report for all other tests was measured at shear rate = 10 sec^{-1}; the viscosity data for this test series alone was not recorded at shear rates less than 25 sec^{-1}).

The swing table motion for this test series was ± 15 degrees from horizontal. The period started at 6.9 seconds during test #1 and gradually decreased to 6.5 seconds by the end of the test series. The reason for the slight increase in speed in unknown, but the small difference in speed should not impact test results. The separator was positioned on the swing table so that the center of gravity of the separator was approximately 5 feet from the center of rotation. The system was positioned relative to the axis of swing to cause the most impact to flows in the influent and effluent lines for the separator.

10.4.3 Test Results. A summary of the conditions and test results for the Sea Motion Test Series on the Alfa-Laval separator system is shown in Table 4. Specific test results are discussed below.

10.4.3.1 Mass Balance Analysis. Figures 14a through 14e illustrate the fluid mass balance between influent and effluents for tests #1 through #5 of this series. As observed during the Crude Oil Test Series, for low oil influent ratios, the bulk of the total flow leaves the system through the water effluent line, but this trend reverses as the oil content in the influent increases. For test #2 (17% oil influent), the oil effluent stream constituted 40% of the total flow, compared to 58% of total flow with an influent oil content of 41% (test #3).

During a later test, it was discovered that the valve controlling drainage from the water effluent tank was not securely closed, and an unknown amount of fluid drained from the tank, unmeasured, during the test. This is assumed to be the cause of the large discrepancy in water effluent flow for test #5, and would explain the low total flow rate for tests #3 and #4. If tests #3 and #4 were affected by this leakage, the water effluent volumes shown in Figures 14c and 14d are low.

During test #5 (100% oil), two samples from the water effluent line contained significant amounts of water (40% and 99%). It is assumed that this was from pockets of water remaining in the lines before the test was started. These two data points were eliminated before averaging the water effluent oil content data for this test.

Water effluent rate data was not collected during test #6 (100% water). However, test #6 is a repeat of test #1, and no significant change in performance is expected between the two tests.

10.4.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 15 shows the oil content of the water effluent stream and water in the oil effluent plotted against influent oil content. Figure 16 shows both water removal efficiency and hydrocarbon removal efficiency as a function of the influent oil ratio for this test series. As in the Crude Oil Test Series, the Alfa-Laval system had 100% hydrocarbon removal efficiency effluent water oil content no greater than the background levels documented in test #1, for all tests except test #5 (100% oil). Water removal efficiencies ranged from 62 to 100%, and averaged 77%, with efficiency increasing with increasing influent oil content. The dashed line in Figure 16 indicates that no intermediate data points exist to determine at what oil/water ratio the hydrocarbon removal efficiency begins to drop off for this system under the specific conditions of this test series.

Water removal efficiencies may be low for tests #3, #4 and #5 as a result of the leak in the water effluent tank drainage line mentioned earlier. If the leak was low, about 5 gpm, the efficiencies shown would be about 2% lower than actual. If the leak was substantial, say 30 gpm, efficiencies could be as much as 18% low. Because a 30 gpm leak would not have gone unnoticed during the tests, it is unlikely that the errors are as high as 18%. However, efficiencies for the affected tests may be a few to several percentage points higher than indicated in the data shown in Table 4 and the mass balance diagrams for tests #3, #4 and #5 of this series.

10.4.3.3 Impact of Separation on Emulsified Water Content. Figure 17 shows the change in emulsified water content between the influent the oil effluent stream for each test in this series. The test #2 and #3 data (17% and 41% oil influent) show only a very small increase in emulsified water content. The emulsified water content data for test #4 (61% oil influent) shows a considerable increase, and there was a moderate increase for test #5 (100% oil). There is no obvious reason for the large increase measured during test #4, except for perhaps the high percentage of oil in the influent for this test. The data in Table 4 shows that the average emulsified water volume in the oil/mousse portion of the effluent oil stream averaged about 2.2% for all tests except #4, where the value jumped to 25.7%. This high percentage was measured in both of the one liter laboratory samples collected during this test, however, and are believed to be representative of conditions during the ten minute test.

10.4.3.4 Impact of Separation on Mean Oil Droplet Size. Mean droplet size decreased in two of the three oil/water tests of this series, but increased slightly in the third. The average mean droplet size for the influent was 4.8 microns and 3.7 microns in the water effluent stream. Figure 18 shows a comparison of mean oil droplet size

in the free water portion of the influent mixture, and the effluent water stream, for each test in this series.

10.4.3.5 Influent and Effluent Line Pressure. Figure 19 shows influent and effluent line pressures for all tests in this series. As with the Crude Oil Test Series results (Figure 13), water effluent line pressures were low and did not fluctuate much with influent conditions. Oil effluent line pressure again was affected by oil content of the influent, generally rising with the oil content in the influent. The oil effluent line pressures for tests #4 and #5 of this series are higher than those seen during the Crude Oil Test Series, probably due to higher actual influent oil ratios and total flow rates in the Sea Motion Test Series. The cause of the influent line pressure fluctuation observed for tests #1 and #2 is unknown.

10.4.3.6 Comparison to Crude Oil Test Series Results. There is no obvious impact on separator performance from sea motion. This was expected with the high g forces involved in the separation method. The fluid mass balance diagrams are similar for both test series for tests #1 and #2, with the exception of test #5, as discussed earlier. Comparisons of oil content of the water effluent, free water content of the oil effluent, and water removal and hydrocarbon removal efficiency between the Crude Oil Test Series and the Sea Motion Test Series for this separator are shown in Figures 20, 21, 22 and 23, respectively. Water removal efficiency was slightly lower for the Sea Motion Test Series, but the difference is small and may be due to the leak in the water effluent tank drainage line discussed earlier. Comparing Figures 12 and 17, the only notable difference in emulsified water volume change is seen in test #4 of the Sea Motion Test Series (61% oil influent). Because the highest oil influent ratio in the Crude Oil Test Series, aside from 100% oil test, was 37%, no conclusive comparison can be made between the tests in these two series.

10.5 Mousse Test Series

10.5.1 Test Plan Modifications. Test #4 (50% mousse) was repeated during this series, and is designated test #4a, because it was believed that the rated capacity of 65 gpm had been exceeded considerably during the original test #4. The test was repeated at a slightly lower flow rate. It was determined later that the original test #4 had been conducted at very near the target flow rate of 65 gpm.

10.5.2 Specific Test Conditions. The target viscosity and emulsified water volume for the mousse to be used for this test series was 40,000-50,000 cP at 60%-70% water. Because of the low viscosity crude oil available to us at this time, however, the viscosity of the mousse in the influent stream (after mixing the mousse with free water to reach the desired influent ratio) averaged about 3500 cP at shear rate = 10 sec^{-1}, 22° C. The average emulsified water volume for this test series was 63%, which met the target value for emulsified water content. There was an increase in viscosity between the mousse supply line (3450 cP average), and after mixing with

water in the recirculating loop (4350 cP at shear rate = 10 sec^{-1}, 20° C), although no significant change in emulsified water volume between the two sampling stations was observed. The interfacial tension test between a sample of the mousse and distilled water was recorded at 33.8 dynes/cm. In comparison, the Vortoil and Intr-Septor systems were tested against much more viscous fluids during the mousse test series, averaging about 27,500 cP at shear rate = 10 sec^{-1}, 16° C.

10.5.3 Test Results. A summary of the conditions and test results for the Mousse Test Series on the Alfa-Laval separator system are shown in Table 5. Mousse property data from the mousse supply line, from the influent mixture line, and from the mousse/oil effluent line after separation are shown in Table 6. Specific test results are discussed below.

10.5.3.1 Mass Balance Analysis. Figures 24a through 24g illustrate the fluid mass balance between influent and effluents for each test in this series. The data shows the same pattern observed in previous test series, of increasing mousse/oil effluent flow volume with increasing mousse/oil content in the influent, again with the exception of the 100% mousse test. The leak through the water effluent tank drainage line valve was discovered between tests #2 and #3 of this series. Therefore, water effluent volumes shown for tests #1 and #2 (Figures 24a and 24b) may be low.

10.5.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 25 shows the mousse/oil content of the water effluent and free water content of the mousse/oil effluent stream plotted against influent mousse content. Figure 26 shows both water removal efficiency and hydrocarbon removal efficiency as a function of the influent mousse ratio for this test series. Hydrocarbon removal efficiency was 100% for the 5% and 23% mousse influent tests of this series, but dropped to 94% and 90% for influents with 49% and 50% mousse, respectively. Hydrocarbon removal performance degraded at the influent mousse ratio of 49%, with effluent water stream at 3-5% mousse/oil for the 49% and 50% mousse influent tests. Water removal efficiency ranged from 62% to 25% for this test series, based on the total amount of free water found in both effluent streams. Figure 26 shows that water removal efficiency dropped with an increase in the influent mousse ratio. Because it is believed that tests #1 and #2 of this series were impacted by the leak through the valve in the drainage line from the effluent water tank, the true water removal efficiencies for these test series may be a few percentage points higher than shown.

10.5.3.3 Impact of Separation on Emulsified Water Content. Figure 27 shows the change in emulsified water content between the influent and mousse/oil effluent stream for each test in this series. Mousse/oil samples for test #2 (5% mousse influent) were too small to test for emulsified water volume. For all other tests except #4 (49% mousse influent), a small to moderate reduction in emulsified water content can be seen in the figure. In test #4 the emulsified water content increased slightly.

10.5.3.4 Impact of Separation on Mean Oil Droplet Size. Mean oil droplet size dropped slightly for the two tests in this series for which the oil content of the water effluent stream could be measured in parts per million. The average mean droplet size for these two tests was 27.0 microns, compared to 21.6 microns for the water effluent stream. Figure 28 shows a comparison of mean oil droplet size in the free water portion of the influent mixture, and the effluent water stream, for each test in this series.

10.5.3.5 Influent and Effluent Line Pressure. Figure 29 shows influent and effluent line pressures for all tests in this series. In contrast with the pressure graphs for the previous test series on the Alfa-Laval, the influent line pressure for the Mousse Test Series is higher during all tests. This may be explained in part by the reduction in mousse content during separation, reducing the total volume of viscous emulsion handled in the lines. Also notable in this graph is the relatively small change in both influent and mousse/oil effluent line pressures, although the trend for mousse/oil effluent line pressure to track with influent line pressure is the same. Another observation worth noting occurred in test #6 (100% water), where influent line pressure remains relatively high after the 100% mousse test (test #5), despite a 100% water influent, although both effluent line pressures dropped back to the lower level observed during test #1 (100% water). The reason for this is not clear.

10.5.3.6 Comparison to Crude Oil Test Series Results. Figures 30, 31, 32, and 33 show comparisons of effluent water mousse/oil content, mousse/oil effluent stream free water content, and water removal and purification efficiencies between the Crude Oil Test Series and the Mousse Test Series for the Alfa-Laval. Figure 32 shows that for mousse influent ratios greater than 23%, water removal efficiency is poorer overall for the Mousse Test Series when compared to the Crude Oil Test Series results. Figures 30 and 33 show that hydrocarbon removal was unaffected by the change from oil to mousse in the influent until the mousse influent ratio jumped from 23% to approximately 50%.

10.6 Mousse With Emulsion Breaker Test Series

10.6.1 Test Plan Modifications. At this time during the test program, it was decided to omit data collection during the second 100% water test included at the end of each series, in the interest of saving time and analysis effort. Therefore, no test #6 results are presented for this or any later tests.

10.6.2 Specific Test Conditions. As in the Mousse Test Series, the mousse viscosities for these tests were much lower than the target value of 40,000 to 50,000 cP because of the thinned crude oil available at the time of the tests. Mousse supply line viscosities for this test series ranged from 2050 cP to 5995 cP and averaged 4420 cP, all at shear rate = 10 sec^{-1}, 20° C, with an average emulsified water volume of 63%. The interfacial tension between the mousse used for these tests and distilled

water was 26.4 dynes/cm, somewhat lower than the 33.8 measured for the Mousse Test Series emulsion.

The emulsion breaker EXXON Breaxit 7877 was added at a rate of 140 ml/min during all tests, excepting only the 100% water test. This corresponds to an average dosage of 540 ppm of the total influent flow for each test. After the addition of the emulsion breaker, the influent mousse viscosity dropped to an average of only 278 cP at shear rate = 10 sec^{-1}, 18° C, over the three tests where this data was obtained. This viscosity is roughly the same as that of the crude oil used during the Crude Oil Test Series on the Alfa-Laval, and is considerably lower than the crude oil used during the Crude Oil Test Series for the other mechanical separators tested.

The target influent ratios for this series were 5, 25, 50 and 100% mousse, but values of 3, 15 and 23 percent were calculated using a mass balance analysis. The normal difficulty in visually determining the mousse/water ratio was aggravated by the presence of residual emulsion breaking chemical which tended to keep a significant amount of small oil droplets suspended in the free water, making a visual determination of mousse content even more difficult.

10.6.3 Test Results. A summary of the conditions and test results for the Mousse With Emulsion Breaker Test Series on the Alfa-Laval separator system are shown in Table 7. Mousse property data from the mousse supply line (before the addition of emulsion breaker), from the influent mixture line (after the addition of emulsion breaker and mixing with free water), and from the mousse/oil effluent line after separation are shown in Table 8.

10.6.3.1 Mass Balance Analysis. Figures 34a through 34e illustrate the fluid mass balance between influent and effluents for tests #1 through #5 of this series. The data shows the same pattern observed in previous test series of increasing mousse/oil effluent flow volume with increasing mousse content in the influent, again with the exception of the 100% mousse test. The figures show no significant change in the total volume of mousse before and after separation for tests #2, #3, and #4. In test #5, however (Figure 34e), approximately 33% of the mousse was demulsified. The majority of the free water passed through the water effluent stream of the separator, although the total flow through this port was 59% mousse/oil. It should be noted that the mass balance analysis for test #3 did not match well with observed mousse to free water ratios, and the data for this particular test is suspect for that reason.

10.6.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 35 shows the mousse/oil content of the water effluent and the free water content of the mousse/oil effluent plotted against the influent mousse ratio for this test series. Figure 36 shows both water removal efficiency and hydrocarbon removal efficiency as a function of the influent mousse content. Water removal efficiency ranged from 50% to 68% and averaged 62% for the tests that included some free water. Water removal efficiency for the 100% mousse test (test #5) was 88%. The 50% efficiency

was calculated for test #3 (15% influent), and appears as a significant dip in the data shown in Figure 36. Because of the poor match between the mass balance analysis and the observed mousse to free water ratios for this test, this data point may not be representative of normal separator performance.

Hydrocarbon removal efficiency was 100% for both the 3% and 15% mousse influent tests, but dropped to 98% for the 23% test (test #4), with mousse/oil content of the water effluent at 0.4%. During test #4, one sample out of 9 from the water effluent line contained 3% mousse/oil, whereas the other samples were observed to contain 99.9% to 100% water with only a thin film of oil on top. If this one 3% mousse/oil sample is eliminated from the data, the hydrocarbon removal efficiency again reaches 100% for this test. The cause of the temporary increase in mousse/oil content in the water effluent stream is unknown.

10.6.3.3 Impact of Separation on Emulsified Water Content. Figure 37 shows low to moderate changes in emulsified water content between the influent and mousse/oil effluent for all tests where the influent was a mixture of mousse and free water. For the 100% mousse test (test #5), however, emulsified water content dropped from 30.6% to 2.1%. This represents an 85% decrease in emulsified water content of the mousse remaining after separation.

10.6.3.4 Impact of Emulsion Breaker on Viscosity. Figure 38 shows the impact that the addition of Breaxit 7877 had on viscosity for each test in this series. In each test, there was a substantial drop in viscosity after the addition of the chemical and mixing. The figure also shows a slight increase in viscosity after separation. The net drop is viscosity is still substantial, however. Comparing these results to the emulsified water content data shown in Figure 37, it is interesting to note that the emulsified water content of the mousse remaining after separation is basically unchanged for these tests, excepting test #5 (100% mousse). This indicates that the drop in viscosity is not associated with a reduction in emulsified water content.

10.6.3.5 Impact of Separation on Mean Oil Droplet Size. An overall but negligible increase in droplet size was observed from the influent to the water effluent. The influent average mean droplet size, including the effect of the emulsion breaker, was only 0.8 microns, compared to 1.7 microns in the water effluent stream. Figure 39 shows a comparison of mean oil droplet size in the free water portion of the influent mixture, and the effluent water stream, for each test in this series. The emulsion breaker is responsible for the very small influent oil droplet size. This was observed during all tests using the emulsion breaker.

10.6.3.6 Influent and Effluent Line Pressure. Figure 40 shows influent and effluent line pressures for all tests in this series. This graph shows a return to the pressure pattern for the Crude Oil Test Series and Sea Motion Test Series, where oil effluent line pressures were higher than influent line pressures, which was reversed during the Mousse Test Series. The other notable difference in this data is the

increase in water effluent line pressure seen during tests #2 and #4. The increase during test #2 is temporary, and the reason for the increase is not clear. The increase observed during test #4 (23% mousse influent) is most likely due to an increase in total flow rate for this test. Pressure data was not obtained during test #5 (100% mousse) in this series.

10.6.3.7 Comparison to Mousse Test Series Results. Figures 41, 42, 43, and 44 show comparisons of the mousse/oil content of the water effluent stream, free water content of the mousse/oil effluent stream, and water removal and purification efficiency between the Mousse Test and Mousse With Emulsion Breaker Test Series. Overall, the separator performed similarly for the two test series for all comparable influent mousse ratios. The most striking difference in the test results was a function of the performance of the emulsion breaker. Most notable were the reduction in viscosity for all tests in the series, and the demulsification noted during the 100% mousse test (test #5). While demulsification was substantial for that test, there was no apparent impact of the emulsion breaker on emulsified water content during the other tests when compared to the Mousse Test Series. Figures 45 and 46 show the emulsified water content data for these two test series on the same page for easier comparison.

10.7 Debris Test Series

10.7.1 Test Plan Modifications. None for this test.

10.7.2 Specific Test Conditions. The crude oil available for the Debris Test Series was slightly higher than that available for previous test series, averaging 536 cP at shear rate = 10 sec^{-1}, 20° C. The debris mixture was added at a rate of 0.065 lb/a minute. The target influent oil ratio for this test series was 25%, but the mass balance analysis and lab samples indicated a higher oil content. The influent ratios calculated from a mass balance analysis using the effluent streams was selected as the most reliable data. The interfacial tension test result for a sample of oil from this test was only 2.8 dynes/cm. However, the only sample tested for interfacial tension in this test series was taken from the oil effluent line instead of the oil supply stream. Residual emulsion breaker in the lines from the previous test is most likely the cause of the this extremely low value for interfacial tension. It is not believed to be representative of actual influent conditions.

10.7.3 Test Results. A summary of the conditions and test results for the Debris Test Series on the Alfa-Laval separator system are shown in Table 9. Specific results are discussed below.

10.7.3.1 Impact of Debris on System Operation. The test series was aborted after 32 minutes of debris addition at the request of the Alfa-Laval operator at the test site. The disk stack was becoming clogged with debris and continuing the test could

have resulted in damage to the separator system. The separator system's sediment ejection device was fired twice during the test - once 20 minutes into the debris addition test, and again at 30 minutes. The sediment ejection had no apparent effect on separator performance.

Pressure in the influent line rose from 38 psi about 18 minutes into test #2, to 55 psi at the time the test was aborted. For the 18 minutes of the test, no significant rise in pressure was recorded. Figure 47 shows influent and effluent line pressures plotted against time for the entire test. The graph shows the increase in influent pressure compared to steady and relatively low pressures for both effluent lines. The graph also shows fluctuations in both effluent line pressures after approximately 20 minutes of debris addition (30 minutes total test time). These appear to correspond with the onset of increasing pressures in the influent line. It should be noted that the influent line pressure for the 100% water test for this test was much higher than in any 100% water test of the previous test series. This may have been the result of test set-up changes required to allow debris addition.

10.7.3.2 Mass Balance Analysis. Figures 48a through 48e illustrate the fluid mass balance between influent and effluents for this test series. Although test #2 was continuous, the oil/water ratio data in these figures have been grouped into ten minute intervals. Figure 48f shows the average performance over the entire test #2 period. These figures illustrate increasing flow rate and oil content of the water effluent with time.

Because the test was abruptly aborted during test period #2.4, the data for the last two minutes that constitute the data for this test are probably not representative. The high influent oil ratio shown in Table 9 (calculated from a mass balance analysis) is probably high from either the influence of the clogged disk stack in the separator system, or could have been the result of the water influent stream being stopped a minute or so prematurely when it became apparent that the test was going to be aborted.

10.7.3.3 Water Removal and Hydrocarbon Removal Performance. Figure 49 shows the effluent water oil content and oil effluent stream free water content plotted against time for test #2 of this series. Figure 50 shows both water removal efficiency and hydrocarbon removal efficiency as a function of time for test #2.

For the first 20 minutes of the test, water removal efficiency ranged from 76% to 84%. A gradual increase in water removal efficiency can be seen in Figure 50. This is reasoned to be the result of the disk stack gradually becoming clogged with debris and restricting the oil effluent flow, thereby sending more of the total effluent out of the water effluent line. The increase in the water effluent rate as a percentage of total flow can be seen in Table 9, where the water effluent rate starts at 34% of total flow at the beginning of the test, and reaches 82% two minutes before the influent flow was stopped. Hydrocarbon removal efficiency started off at 100%, but began to degrade after 18 minutes of debris addition as shown in Figure 50.

10.7.3.4 Impact of Separation on Emulsified Water Content. Figure 51 shows little change in emulsified water content between influent and oil effluent streams over the entire test series.

10.7.3.5 Impact of Separation on Mean Oil Droplet Size. An increase in mean droplet size was observed during the first two test periods of test #2. The average mean oil droplet size in the influent for these periods was 0.5 microns compared to 4.4 microns in the water effluent stream. However, droplet size was very low (0.5 microns) for these test periods (the first 20 minutes of the test), and may have been due to residual emulsion breaking chemical in the lines. After 20 minutes of debris addition, there was a large amount of oil in the water effluent stream, making droplet size analysis meaningless. Figure 52 shows a comparison of mean oil droplet size in the free water portion of the influent mixture, and the effluent water stream, for the Debris Test Series.

10.7.3.6 Comparison to Crude Oil Test Series. Figure 53 shows a comparison of water removal and hydrocarbon removal efficiencies between the Crude Oil and Debris Test Series. For the first 20 minutes of the Debris Test Series oil and debris addition test, water removal efficiency was comparable to that observed during the Crude Oil Test and Sea Motion Test Series for comparable oil influent ratios.

10.8 Observations on Operability, Reliability, Maintenance, Safety and Transportation

10.8.1 Operability. The system was fairly simple to operate once set up for the tests, but did require a knowledgeable operator for the initial assembly of the centrifuge itself. This included selecting and installing the appropriate gravity disk and installing the disk stack in the centrifuge in preparation for operation. The system is designed for simplified assembly and includes built-in physical indicators, such as raised dots of metal on components, that indicate proper alignment of the centrifuge components.

During actual operation of the system, no significant operator attendance was required. For optimum separation performance, however, the attending operator would typically collect effluent samples for analysis and modify either the system configuration (by changing gravity disks, if warranted), or manipulate the effluent rates, to improve performance. Independent of fine tuning separator performance, some level of monitoring is still required to ensure that there are no operating problems with the system. Other Alfa-Laval systems include remote monitoring capabilities, with alarm lights to notify operators of problems, for example, and it should be fairly simple to incorporate an alarm system that would work within the operating scenario of the U.S. Coast Guard and MSRC recovery operations.

A moderate amount of training and practice would be required before someone could use the system on their own. Alfa-Laval leases their centrifuge systems, but always provides Alfa-Laval operators with the leased gear.

It also must be noted that due to the high rpm of the centrifuge, a start-up time of roughly 35 minutes is required before the system is ready for operation. Once

separation operations are completed, it takes another 45 minutes or so for the centrifuge to come to rest.

10.8.2 Reliability. During the tests, no downtime was noted because of reliability problems with the centrifuge unit. During the Debris Test Series, however, the test series had to be aborted because the disk stack was becoming clogged with debris. (See the previous discussion on Debris Test Series results for more complete information). Continued operation of the unit could have resulted in damage to the system.

During the tests that involved large fractions of mousse in the influent, the feed pump was strained and was observed to slow down on occasion. A higher capacity pump would be required to prevent a slow down in separation operations under influent conditions that include high ratios of viscous fluids.

10.8.3 Maintenance. The only maintenance operation conducted on the Alfa-Laval system during the tests was cleaning the disk stack after the Debris Test Series and preparing the unit for transport. Removing and cleaning the disk stack took approximately 4 man-hours. This level of maintenance would not be required in between individual operations with the system unless the stack were clogged. Before transport, however, the disk-stack does need to be removed and secured to prevent damage during transit.

10.8.4 Safety. No safety problems were observed with operation of the unit.

10.8.5 Transportability. The unit was relatively easy to transport due in part to the containerization of the centrifuge unit. Both the base unit and centrifuge unit bases are designed for lifts with forklifts, and the feed pump was easily lifted by forklift as well. Because of the large weight of the containerized centrifuge unit (11,300 lbs) however, a high capacity forklift was required for placement of the system.

10.9 Summary and Manufacturer's Input on Alfa-Laval OFPX 413

10.9.1 Summary of Strengths and Weaknesses. The Alfa-Laval's main strength is its ability to produce extremely pure water under most influent conditions. It also puts effluent streams out under pressure. This is advantageous in that additional pumps may not be required to transport oil/mousse effluent streams to storage devices, or for over-boarding water effluent streams.

The primary weaknesses observed during these tests were the high weight to capacity ratio of the unit, the low water removal efficiencies observed for all influent conditions, and its inability to handle either a 100% oil/mousse or 100% water influent stream effectively. The system was susceptible to damage from the intake of debris, and debris also significantly decreased hydrocarbon removal performance.

10.9.2 Manufacturer's Input. Based on the test results, Alfa-Laval has recommended the following improvements and modifications to the system to produce a unit capable of more closely meeting the operational requirements of the U.S. Coast Guard and MSRC:

1) To improve the weight to capacity ratio, Alfa-Laval proposes substituting some of the stainless steel in the system with fiberglass, and using aluminum for the skids instead of steel. Alfa-Laval believes that a weight of 7000 lbs for the containerized centrifuge unit might be possible with these substitutions. This represents a savings of approximately 25% in total system weight.

2) Overall flow rate and water removal efficiency could be improved by redesigning the effluent pumps internal to the centrifuge system. Alfa-Laval Engineering is presently investigating this and reports that the technology will be available in the near future.

3) A first-stage surge tank or "wrinkle tank" was recommended by Alfa-Laval to prevent the occurrence of a 100% oil or mousse influent.

3) Alfa-Laval also proposes incorporating a self-cleaning strainer in the feed stream to remove any debris. This should produce separation with water quality results comparable to the other tests performed on the separator.

11.0 SURGE TANK SYSTEM CHARACTERISTICS AND TEST RESULTS

11.1 System Information

11.1.1 System Description and Principle of Operation. A simple gravity "surge" tank was included in the test program to determine the benefit of adding a first stage surge tank to any one of the other mechanical separators. By quantifying the water effluent characteristics, which would then form the influent characteristics for any of the more sophisticated separators, a "paper" analysis of the value of a hybrid system could be completed.

To expedite design, fabrication and procurement of a surge tank for the test program, it was decided to procure and modify an existing gravity separator with a 1000 gallon volumetric capacity, to provide a four minute resident time at the 250 gpm target flow rate. A Flo Trend IPL Phase[3] separator with a rated flow capacity of 100 gpm was procured and modified. The separator's coalescer plates were removed to increase flow capacity. Although the plates improve separation, they would significantly reduce the flow capacity of the unit, especially for thick and viscous emulsions, and were not needed to simulate a simple first stage surge tank. The surge tank also included baffles to reduce free surface effects inside the surge tank and facilitate separation, a removable debris screen, and removable top covers to allow

cleaning of the debris screen. A photograph of the surge tank at the test site is shown in Figure 54.

Because the separator was modified and then tested at 2.5 times the original rated capacity, the test results presented in this report for the surge tank should in no way be considered to reflect the performance of a production model Flo Trend separator.

The six inch influent port, also shown in Figure 54, deposits the influent near the top inside the surge tank where the influent then passes through a series of three vertical baffles. The middle portion of the tank is unrestricted and provides time for settling and separation. After the settling area, the fluid passes through the removable debris screen and towards the oil and water outlets. A U-shaped weir mounted about one quarter of the total height from the top and perpendicular to fluid flow, collects oil and directs it to a two inch diameter oil effluent port on the side of the surge tank. Past the oil weir, an adjustable water weir controls water flow, which exits the tank through a six inch port at the bottom of the tank opposite the influent port.

11.1.2 Dimensions, Capacity, Power Requirements, and Special Logistics Characteristics. The system is a single unit configured with forklift slots in its base for easy transportability. An added benefit of the large open volume and removable top covers is the internal space available for storing ancillary oil spill response equipment, such as hoses or booms.

Surge tank dimensions, weight, and power requirements are shown in Table 10. Because the system was modified for use as a simple 250 gpm capacity gravity surge tank, 250 gpm was used as the target flow capacity for the tests. The total weight of the unit as modified was 3600 lbs, which represents its total system weight as it requires no power system. The weight to capacity ratio for the surge tank is 14, using the 250 gpm flow rate.

11.2 Test Set-Up for Surge Tank. A schematic layout of the test set-up for the tests conducted on the surge tank are shown in Figure 55. Two 400 gallon intermediary tanks used to capture the water and oil effluent streams before pumping to the reclaimed oil and water effluent tanks. The surge tank is greatly impacted by back pressure on either effluent line, requiring the use of the intermediary tanks for these tests.

The debris screen was removed for these tests to improve flow through the tank, as it had already been determined at this point in the test program that the debris test would be omitted for the surge tank in the interest of time. The adjustable weir was set at its highest setting for both test series.

11.3 Crude Oil Test Series

11.3.1 Test Plan Modifications. None for this test series.

11.3.2 Specific Test Conditions. This test series was conducted on two different days, with different oil viscosities. Tests #1 through #5 were conducted with viscosity averaging 333 cP at shear rate = 10 sec^{-1}, 21° C, and tests #6 through #8 (the reduced capacity tests) were tested with a 1360 cP (shear rate = 10 sec^{-1}, 17° C), viscosity oil. The interfacial tension test result of 7.2 dynes/cm was recorded for a sample taken the second day of testing. No sample from the first day of testing was analyzed for interfacial tension with water.

Test #5 (100% oil) was aborted because the surge tank was unable to handle 100% oil while attempting this test, oil began leaking from beneath the top covers of the tank.

11.3.3 Test Results. A summary of the conditions and test results for the Crude Oil Test Series on the surge tank is shown in Table 11. Specific test results are discussed below.

11.3.3.1 Mass Balance Analysis. Figures 56a through 56g illustrate the fluid mass balance between influent and effluents for each test of this series. Figures 56a and 56b show that for 100% water or low influent oil fractions (5%), a considerable amount of water left the system through the oil effluent port. Figures 56c and 56d show that for greater influent oil fractions, the oil effluent is 100% oil, but at such low flow rates that a considerable amount of oil leaves the system in the water effluent. This is probably due to restrictions in the oil effluent route, which are believed to have negatively impacted the results of both test series on the surge tank. The primary obstruction to oil effluent flow is the two inch diameter oil effluent port, which was not modified from the 100 gpm capacity Flo Trend production model separator. If a larger diameter outlet had been installed to better match the 250 gpm capacity, the flow may have been considerably larger, providing better performance.

Another impediment to the oil effluent stream was the effluent hose. During test #3 of the series, the effluent hose was shortened by removing an unnecessary 10 ft section, and a vertical bend in the hose was eased to provide a straighter path for the fluid. While the improvement in flow rate was visible, it did not have a significant impact on surge tank performance.

Figures 56f and 56g show the fluid mass balance for the reduced capacity tests of this series. Comparing these to Figure 56b, which shows results from the full capacity test at a similar oil influent ratio, there is no significant impact when capacity is reduced to approximately 50% (Figure 56f). When the capacity is reduced to approximately 30% (Figure 56g), however, a significantly greater portion of the flow leaves the system through the water effluent, without any significant impact on separation. This has the net effect of improving water removal efficiency only.

11.3.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 57 shows the oil content of the water effluent stream and the free water content of the oil effluent stream plotted against influent oil content for the full capacity tests of this series. Figure 58 shows both water removal and purification efficiency as a function of the influent oil ratio for the same tests. Water removal efficiency significantly improved with increased oil content, but hydrocarbon removal dropped from 40% to less than zero, because of a greater oil content in the water effluent that in the influent.

11.3.3.3 Impact of Separation on Emulsified Water Content. Figure 59 shows the change in emulsified water content between the influent and oil effluent for each test in this series. The recorded change in emulsified water volume for each test is very small and does not represent a significant in emulsified water content throughout this test. The relatively high emulsified water content value (9.1%) shown for the influent (and hence effluent) for the 6% oil influent, 124 gpm test (test #7), could have been caused by the influent being subjected to more cycles through the centrifugal pump in the recirculating/mixing loop of the test set-up. Since the speed of that pump was not modified with influent flow rate changes, a reduction in influent flow rate would proportionally increase the number of cycles through the recirculating loop. Because there is no influent data for the second reduced capacity test (4% oil influent, 76 gpm), this hypothesis cannot be tested against that data, where a high influent emulsified water content would be expected if the number of cycles through the centrifugal pump is the cause of the emulsification.

11.3.3.4 Impact of Separation on Mean Oil Droplet Size. Because the oil content of the water effluent stream was measurable in large quantities for each test in this series and was not dispersed in the free water, a comparison of droplet size is not meaningful for these tests.

11.3.3.5 Influent and Effluent Line Pressure. Figure 60 shows the influent line pressure for all tests of this series. Because open tanks were used to capture both effluent stream flows, the influent line pressure also represents the pressure drop across the surge tank. Influent line pressure appears to be insensitive to the oil content in the influent, and only influenced by the influent flow rate.

11.3.3.6 Impact of Reduced Capacity. Figure 61 shows the impact of reduced capacity on water removal and hydrocarbon removal for the surge tank with an influent oil content of approximately 5%. Water removal performance was not impacted until capacity dropped to 30%, and then only a moderate increase in efficiency was observed. In comparison, hydrocarbon removal performance dropped drastically as influent flow was reduced. These results were unexpected, as it was reasoned that the longer residence time resulting from the reduced flow rate would improve separation performance.

11.4 Sea Motion Test Series

11.4.1 Test Plan Modifications. Test #5 (100% oil influent) was cancelled because the surge tank was unable to handle a 100% oil influent at 250 gpm during the Crude Oil Test Series.

11.4.2 Specific Test Conditions. The crude oil used for these tests had an average viscosity of 945 cP at shear rate = 10 sec^{-1}, 17° C, and the interfacial tension test result for the oil was only 3.9 dynes/cm. The simulated sea motion rocked the surge tank at $\pm$ 15° from horizontal at a period of 6.9 seconds. The surge tank was positioned with the axis of flow perpendicular to the axis of motion.

11.4.3 Test Results. A summary of the conditions and test results for the Sea Motion Test Series on the surge tank is shown in Table 12. Specific test results are discussed below.

11.4.3.1 Mass Balance Analysis. Figures 62a through 62d illustrate the fluid mass balance for tests #1 through #4 of this series. On average, only 2% of the total flow left the surge tank in the oil effluent stream, independent of the influent oil content. While the oil effluent averaged 92% oil over the three tests containing oil in the influent, and reaching 100% oil for the 36% and 52% influent oil tests, the oil effluent flow rate was so small that there was no appreciable reduction in the oil content of the water effluent stream over the influent.

11.4.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 63 shows the oil content of the effluent water stream and the free water content of the effluent oil stream plotted against the influent oil ratio for this test series. Figure 64 shows both water removal efficiency and hydrocarbon removal efficiency as a function of the influent oil ratio for this test series. Water removal efficiency is extremely high and gradually increases with increasing influent oil content, but again with very low effluent oil flow rates. Hydrocarbon removal efficiency starts out very poor at only 14% and drops to near and below zero for the other tests, indicating no hydrocarbon removal from the surge tank at all.

11.4.3.3 Impact of Separation on Emulsified Water Content. Figure 65 shows an insignificant change in emulsified water content between the influent and oil effluent stream for each test in this series.

11.4.3.4 Impact of Separation of Mean Oil Droplet Size. Because the oil content of the water effluent stream was measurable in large quantities for each test in this series and was not dispersed in the free water, a comparison of droplet size is not meaningful for these tests.

11.4.3.5 Influent Line Pressure. Figure 66 shows the influent line pressure for each test of this series. As observed during the Crude Oil Test Series, influent line pressure appears to be influenced only by the influent flow rate and not at all by the oil content of the influent.

11.4.3.6 Comparison to Crude Oil Test Series. The performance of the surge tank was impacted by simulated sea motion, reducing hydrocarbon removal efficiency and improving better water removal efficiency. Figures 67, 68, 69, and 70 show comparisons of water effluent oil content, oil effluent stream free water content, and water removal and purification efficiency, respectively, between the Sea Motion and Crude Oil Test Series results for the surge tank. The improvement in water removal efficiency is most likely the result of even lower flow through the oil effluent stream due to the simulated sea motion, causing most of the flow (and hence most of the water) to flow through the water effluent port. The motion periodically changes the level of the fluid inside the surge tank at the location of the oil weir, preventing fluid from topping the weir when that end of the surge tank is above the horizontal position. Hydrocarbon removal was also probably impaired by the motion which impedes separation by encouraging continued mixing of the oil and free water.

11.5 Observations on Operability, Reliability, Maintenance, Safety and Transportation. The surge tank has no moving parts, is extremely easy to set up and operate, and showed no reliability problems. No safety problems were observed. The unit is extremely easy to transport due to its light weight and the forklift slots built into the unit. The inside of the surge tank could provide valuable stowage space for hoses, booms or other equipment that would need to be transported to a spill site. The surge tank is easy to maintain, as well, because the removable top covers make removal of the debris screen and interior cleaning very simple tasks.

11.6 Summary of Strengths and Weakness and Recommended Improvements to Enhance Performance. The only appreciable strength of the surge tank as configured for these tests is its light weight and low weight to capacity ratio. While water removal efficiencies were quite high under most influent conditions, with very little water in the oil effluent stream, the oil effluent flow rate was so low that no significant amount of oil was removed, resulting in poor effluent water quality. Hydrocarbon content of the effluent water was often equal to or poorer than that of the influent. Separation was also negatively impacted by simulated sea motion.

The performance of the surge tank might be significantly improved by increasing the size of the oil effluent port. This would allow a greater proportion of the flow to exit the tank in the oil effluent stream, reducing the amount of oil forced out through the water effluent port. A tank capable of withstanding a small internal pressure also would help force oil out the oil effluent port, and would allow the tank to be completely filled, eliminating the free surface effects most responsible for continued mixing when the tank is subjected to motion. An analysis of the fluid flow hydraulics, resulting in design modifications to the surge tank, are recommended.

12.0 VORTOIL SYSTEM CHARACTERISTICS AND TEST RESULTS

12.1 System Information

12.1.1 System Description and Principle of Operation. Conoco Specialty Products, Inc.'s Vortoil Oilspill Separation System is a three stage separation system incorporating a first stage surge tank and two hydrocyclone separation stages. A photograph of the Vortoil system is shown in Figure 71.

The influent is fed to a 275 gallon surge tank after passing through a duplex strainer to filter out debris. The surge tank allows for gross separation of the oil and water and provides some resident time for emulsion breaker or other additives to take effect. From the bottom of the surge tank, fluid is pumped by a Desmi DOP 250 Archimedean Screw pump through a finer single strainer, and then to the first stage of Vortoil hydrocyclones. Each set of hydrocyclones consists of multiple individual hydrocyclones set up in parallel to process the influent. The individual hydrocyclones are long conical tubes with involute inlets designed to initiate cyclonic forces inside the tube that effect the separation of oil and water. Inside each hydrocyclone, the low pressure at the center created by the internal "cyclone" draws the oil to form a core of oil which, again because of low pressure, exits the tube through a small hole near the inlet. The water, thrown to the outside of the "cyclone", is discharged near the opposite end of the hydrocyclone. The oil effluent from the first stage of hydrocyclones is returned to the surge tank. The water effluent is sent to the second stage of hydrocyclones for further separation. The oil effluent from the second hydrocyclone stage also is returned to the surge tank, and the water effluent finally leaves the system through the water effluent port. All oil effluent leaves the system through a port at the top of the surge tank.

A level control device is used in the surge tank to ensure that a suitable oil/water mixture ($\leq$ 15% oil) is fed to the hydrocyclones. The level controller monitors the interface between the oil/mousse and free water in the tank. When the interface drops, indicating an insufficient amount of free water is available directly from the influent, a portion of the clean water from the water effluent of the hydrocyclones is automatically routed to the surge tank.

An optional chemical injection package is available with the system which injects emulsion breaker into the influent stream upstream of the duplex strainer and surge tank.

12.1.2 Dimensions, Capacity, Power Requirements and Special Logistics Characteristics. The entire system is configured in a single unit, with the exception of an external hydraulic power source. System dimensions, weight, and power requirements are shown in Table 13. The manufacturer's rated capacity for this unit is 250 gpm, although this only represents the upper limit for the water effluent. The true total capacity of the unit is the 250 gpm water effluent rate plus whatever oil is brought into the system through the influent port. During tests, however, the system was able to handle a maximum of approximately 205 gpm of pure water, due to pump

limitations. The manufacturer's representatives believed that this may have been the result of less than full hydraulic pressure (3000 psi) in the hydraulic power system used to run the system, but identical pumps used in the test set-up were able to produce greater than 400 gpm flows using the same hydraulic power sources. An exact reason for the reduced capacity at 100% water was not identified during the tests. The highest sustained flow rate observed for oil/water mixtures processed by the Vortoil system during the test program was 280 gpm. Because the cause of the reduced capacity at 100% water could not be positively identified, the manufacturer's rated capacity of 250 gpm is shown in Table 13 and was used for the weight to capacity ratio calculation.

Although relatively large in area and volume, the separator system weighs only 7280 pounds without the external power pack, due in part to the use of fiber reinforced plastic (FRP) for the surge tank. The system was easily transported by truck and positioned using a forklift.

In addition to the hydraulic power source required to run the Desmi pump integral to the system, compressed air and 110 volt AC power are required to run the level control instrumentation on the system.

12.2 Test Set-Up for Vortoil. A schematic layout of the test set-up for all Vortoil test series is shown in Figure 72. The facilities needed to test this separator included one 400 gallon intermediary tank used to capture the oil effluent stream before pumping to the reclaimed oil tanks. During initial tests on the system, the oil effluent line led directly to the reclaimed oil tank. The combination of the length of hose for the oil effluent line (estimated at approximately 50 feet), and a rise in elevation from the top of the Vortoil surge tank to the reclaimed oil tank led to an unacceptable back pressure placed on the oil effluent stream. The Vortoil oil effluent line is fitted with a 40 psi rupture disk to prevent over- pressurization within the surge tank. This disk ruptured as a result of the back pressure placed on the oil effluent stream, and led to the use of the intermediary tank to capture the oil effluent stream before it was pumped to the reclaimed oil effluent tank. The water effluent stream did not require the use of an intermediary tank, and was routed directly through the test sampling station and into the water effluent tank.

The Vortoil system controls can be adjusted to provide better water quality at the expense of water removal, or vice versa. For this test program, Vortoil personnel decided to set the controls on the system to provide a balance between water removal and hydrocarbon removal over the large range of oil/water influent ratios expected during the tests.

12.3 Crude Oil Test Series

12.3.1 Test Plan Modifications. The modified Crude Oil Test Series plan, incorporating one sea motion test, was adopted for this test. In addition, during the reduced capacity 25% oil test (original test #3), it was decided to test the separator with the Vortoil recirculating pump at both full and reduced capacity. Reduced

recirculating pump capacity allows for a longer residence time for the influent in the surge tank. Test #3.1 conditions were 24% oil influent, 53% system capacity and reduced capacity of the pump. Test #3.2 conditions were 28% oil influent, 49% system capacity and full pump capacity. The influent oil ratio was modified from 50% to 25% target for this test to compare results to the other 25% oil influent tests conducted on this separator. Test #7 (100% oil) was cancelled due to a shortage of crude oil at the test site after completing tests #2 through #6 of this series.

12.3.2 Specific Test Conditions. Test #6 was the simulated sea motion test, with motion at $\pm$ 15° from horizontal at a period of 6.9 seconds.

The viscosity of the oil used during this test averaged 883 cP at shear rate = 10 sec^{-1}, 18° C, and the interfacial tension test result was 27.3 dynes/cm.

12.3.3 Test Results. The Vortoil system's oil effluent stream is not steady, as it is partially dependent on the integral level control mechanism for the surge tank. Figure 73 is a reproduction of the real-time graph of test data for the 27% oil full capacity test (test #4) of the modified Crude Oil Test Series, showing flow rates, in-line temperature, and pressures for the test. The periodic nature of the oil effluent flow, which showed large fluctuations over four intervals of about 2.5 minutes each, can be seen in this figure. This graph shows an extreme example of the fluctuation, and was selected only to illustrate the nature of the flow. The surging nature of the effluent oil stream may allow for greater separation inside the surge tank when oil effluent flow is low or stopped. Both the surging flow rate and its possible effect on separation inside the surge tank impact the reliability of mass balance analyses performed on the data from this separator. The oil/water ratio data collected from this stream was extremely unsteady over test periods #3.1 and #3.2, with oil content varying from 100% to 42% under the same test conditions. In addition, flow periodically stopped completely during these tests.

A summary of the conditions and test results for the Crude Oil Test Series on the Vortoil separator is shown in Table 14. Specific test results are discussed below.

12.3.3.1 Mass Balance Analysis. Figures 74a through 74g illustrate the fluid mass balance between influent and effluents for each test in this series. The test #1 diagram (Figure 74a) is particularly notable, as it illustrates the ability of the Vortoil to effectively process influent streams of 100% water. The Vortoil was the only system tested that demonstrated this capability.

Test #5 was intended to be a 50% oil test at full capacity. There is conflicting data regarding the oil influent ratio, and the 76% ratio shown is from a mass balance analysis, which matched well with the laboratory sample data (70%) for this test. Graduated cylinder data for this station averaged 36% over the test. A mass balance analysis of the effluent streams indicated an influent oil ratio of over 70%, so the 76% value from the mass balance analysis was assumed for the table and analysis on page 1. It also was noted that it took an inordinate amount of time for us to reach what we believed was a 50% oil mixture at the influent sampling station. During the first

half of test #5, the water effluent samples were observed to be 100% oil at extremely low flow rates. Samples from the Vortoil system's internal sampling port between the two hydrocyclone vessels showed low oil content as expected. Approximately eight minutes into the test, the oil content of the water effluent stream abruptly dropped from 100% oil to an average of 6% oil for the next two minutes, and then to less than 1% for the remainder of the test. This coincided with an abrupt increase in water effluent flow rate. Water effluent samples taken from between the two hydrocyclone vessels showed a typical amount of oil in them - nowhere near the 86% observed at the effluent line. Conoco representatives were not sure why this was happening. Immediately previous to test #5, the test series was halted so that Vortoil personnel could install a check valve on the oil effluent line to prevent a siphoning effect on the discharge and any resulting suction force on the surge tank, but this should have had no impact on the water effluent stream. Because of the poor ability to control the test parameters for this test series, and the unusual effluent quality from the Vortoil that didn't match the samples taken from between the two hydrocyclone stages, the data from this test is believed to not be representative of system performance.

Although test #7 (100% oil influent) was aborted for this series due to a shortage of oil at the test site as the oil rate was increased towards 250 gpm in preparation for test #7, no oil was observed in the water effluent line. This matched previous experience with calibration runs conducted earlier in the week on the Vortoil system, during which no flow was observed in the water effluent line when the influent consisted of 100% oil. As with the 100% water influent, the Vortoil system was the only separator tested that was able to demonstrate this capability.

12.3.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 75 shows the oil content of the water effluent stream and the free water content of the oil effluent stream plotted against the influent oil content for the 100% capacity, stationary tests of this series. Figure 70 shows the water removal and hydrocarbon removal efficiencies for the same tests. Again, the data points at 76% influent oil content are not believed to be representative of typical separator performance, as discussed in the previous section. At 100% system and pump capacity, the separator performed very well in regards to both water removal and hydrocarbon removal for all oil influent ratios, with the exception of the test #5, 76% oil influent. Excluding test #5 data, water removal efficiency for full capacity tests ranged from 85% to 100%. Hydrocarbon removal efficiency was consistently 100% excluding only tests #5 and #6, for which the anomalous results are unexplained, as previously discussed.

12.3.3.3 Impact of Reduced System Capacity, Reduced Recirculating Pump Capacity, and Sea Motion. Figure 77 illustrates the impact that reduced system capacity, reduced recirculating pump capacity, and sea motion had on water removal and hydrocarbon removal efficiencies. The influent oil content for the four tests compared in the figure ranged from 20% to 28%, averaging 25%.

The figure shows that sea motion had no significant impact on water removal, actually showing a somewhat higher efficiency for water removal under the simulated

sea motion conditions. The higher efficiency water removal efficiency for the sea motion test is most likely to be from the lower influent oil content for this test. This follows the pattern of decreasing water removal efficiency with higher influent oil contents observed in all of the tests on the Vortoil. Hydrocarbon removal efficiency dropped from 100% for the stationary test to 92% under the motion conditions, with the oil content of the water effluent at 2%. Although some of the oil in the water effluent lines could have been residual from test #5 (see above), the oil content in the water effluent line was observed to increase from 1% to 3% over the course of the ten minute test. While the hydrocyclones should not be impacted by the sea motion because of the large centripetal force produced inside the hydrocyclones, the surge tank may have been affected, thereby affecting the quality of the influent drawn from the surge tank into the hydrocyclones.

Figure 77 also shows that reduced system capacity had no impact on hydrocarbon removal, independent of the pump capacity. Both values for hydrocarbon removal efficiency in the reduced system capacity tests were 100%, equal to that at full capacity with the same influent oil content. Water removal efficiency was negatively affected by reduced system capacity, and even more when coupled with reduced recirculating pump capacity. Because lower influent flow rate should increase the resident time within the surge tank, thereby improving separation performance, these results were unexpected. Conoco explained[8] that for the reduced capacity test at full pump speed, there is a high recycle rate of water from the hydrocyclones that tends to inhibit settling in the surge tank, and may be responsible for the reduction in performance for test #3.2. (Proposed modifications to the system will reduce this impact. This is discussed in more detail later in this report.) Conoco also suggested that reduced water removal performance for the reduced recirculating pump speed test could be due to the pump actually being set at higher than one half speed, since there was no method at the test site for accurately setting pump speed. This is supported by the data in Table 14, which shows a 34% reduction in the effluent water stream (as percentage of total fluid flow) for the reduced capacity test with reduced recirculating pump speed (test #3.2) compared to the full capacity test under similar influent conditions (test #4). If both influent flow and internal pump speed were reduced in proportion, the fraction of total flow leaving the system through the water effluent would be expected to remain the same for both tests. If the pump was indeed operating at greater than one half speed, the recirculation of effluents to the surge tank could be preventing settling as hypothesized for test #3.1. Also, since effluent oil flow was not controlled and surge tank pressure was not monitored, the interface level in the tank may have risen at reduced flow rates, reducing the residence time for the oil/mousse in the surge tank[8]. Another factor suggested[8] was that the speed of the centrifugal pump in the recirculating loop was not reduced for the reduced capacity tests, creating higher shears and perhaps higher emulsification. However, there was no significant change in the emulsified water volume in the influent between the full and reduced capacity tests to support this.

12.3.3.4 Impact of Separation on Emulsified Water Content. Figure 78 shows the increase in emulsified water content between the influent and oil effluent stream for each test in this series. The figure shows substantial increases in emulsified water content for all tests, up to a ten-fold increase for some.

In separator systems where there is contact between the bulk oil and bulk water during separation, such as simple centrifugal separators and hydrocyclone systems, increases in emulsification can be expected caused by the shear at the surface between the oil and free water inside the centrifuge or hydrocyclone[6]. Oil effluent from the hydrocyclones may have been emulsified inside the hydrocyclone before recycling to the surge tank for discharge. In addition, mixing occurring within the surge tank because of the recycled stream velocities may be a contributing factor to the total increase in emulsified water volume for this separator. As mentioned earlier, Conoco has proposed modifications to reduce the velocity of recycled streams entering the surge tank to reduce this mixing process.

12.3.3.5 Impact of Separation on Mean Oil Droplet Size. The average mean oil droplet size decreased from 7.5 microns in the influent to 2.5 microns in the water effluent stream for those tests where the oil content of the water effluent stream was measurable in parts per million. The data in Table 14 shows that oil droplet size dropped consistently for each test in this series. Figure 79 shows a comparison of mean oil droplet size in the free water portion of the influent mixture, and the effluent water stream, for each test in this series.

12.3.3.6 Influent and Effluent Line Pressure. Influent and water effluent line pressures for the Crude Oil Test Series are shown plotted against total test time in Figure 80. The effluent oil stream was captured in an open intermediary tank, and therefore pressure at that effluent port was zero for all tests. Figure 80 shows a straight line for the 100% water influent test (test #1), but spikes in all following tests. The figure also shows that influent and water effluent pressures are inversely related - as influent pressure increased, effluent water pressure dropped. Influent line pressure increased with increased oil content in the influent.

It should be noted that no other test results on the Vortoil system show pressure spikes of the magnitude recorded in this test series, and these may be the result of conditions within the system during the first test, rather than the result of the influent or operating conditions. Difficulties with the automatic level controller were noted by Conoco personnel on the second day required to complete these tests. These problems may have been the cause of the pressure spikes, and also may have had an impact on separator performance.

The pressure fluctuations shown in the figure are assumed to be caused by the internal adjustments made to system operation on cue from the level control mechanism inside the surge tank, which impacts water effluent flow rate as well as the volume of fluid recycled to the surge tank from the hydrocyclone water effluent line. In particular, for tests where the water influent fraction was low, as in test #5, a great portion of the water effluent is recycled to the surge tank to ensure that

unacceptably high concentrations of oil are not pumped to the hydrocyclones. This explains the water effluent line pressure drop for test #5. Similarly, in the reduced capacity tests, #3.1 and #3.2, a greater amount of the hydrocyclone water effluent stream is being recycled back to the surge tank, decreasing the flow and pressure in the water effluent line. A greater recirculation back to the surge tank would increase the pressure seen in the influent line, as the influent tries to overcome the volume of fluid already in the surge tank by forcing fluid out the oil effluent line.

12.4 Mousse Test Series

12.4.1 Test Plan Modifications. None for this test series.

12.4.2 Specific Test Conditions. The average viscosity for the mousse used in this test series was 27,463 at shear rate = 10 sec^{-1}, 15° C, with emulsified water volume at 55.3%. The interfacial tension test result for a sample of the mousse from the mousse supply line was 27.3 dynes/cm.

12.4.3 Test Results. A summary of the conditions and test results for the Mousse Test Series on the Vortoil system is shown in Table 15. Mousse property data for samples from the mousse supply line, from samples after mixing in the influent line, and from the mousse/oil effluent stream after separation are shown in Table 16. Specific test results are discussed below.

12.4.3.1 Mass Balance Analysis. Figures 81a through 81e illustrate the fluid mass balance between influent and effluents for each test of this series. These figures show that the Vortoil was extremely effective at bulk separation of mousse from free water, even when the influent stream was 100% water (test #1) or 100% mousse (test #5).

12.4.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 82 shows the mousse/oil content of the water effluent stream and the free water content of the mousse/oil effluent stream plotted against the influent mousse content for this test series. Figure 83 shows water removal and purification efficiency as functions of the influent mousse content. The Vortoil system performed extremely well here, with hydrocarbon removal efficiency consistently at 100%, and mousse/oil content of the water effluent stream consistently below that of the background levels recorded for test #1 (100% water influent). Water removal efficiency was consistently 96% or better, showing a slight decrease with increased influent mousse content.

12.4.3.3 Impact of Separation on Emulsified Water Content. Figure 84 shows very small changes in emulsified water content between the influent and mousse/oil effluent stream for each test in this series. The mousse content of the influent stream sample for the 15% influent test (test #2) was too small to conduct an emulsified water volume analysis.

12.4.3.4 Impact of Separation on Mean Oil Droplet Size. The average mean oil droplet size decreased from 26.1 microns in the influent to 5.7 microns in the water effluent stream. The large decrease is mean droplet size was consistent across all tests of this series, as illustrated in Figure 85. No data is shown for the 100% mousse influent test, because no water effluent stream was produced during the tests. This is also illustrated in Figure 81e, the mass balance figure for this test.

12.4.3.5 Influent and Effluent Line Pressure. Figure 86 shows influent and water effluent line pressures for this test series. As observed during the Crude Oil Test Series, water effluent line pressure drops and influent line pressure increases as mousse or oil influent content increases, presumably due to a greater amount of water being recirculated back to the surge tank. In contrast to the pressure graph for the Crude Oil Test Series (Figure 80), no pressure spikes were recorded in these tests, which may have been caused by problems with the level controller mechanism, discussed previously.

12.4.3.6 Comparison to Crude Oil Test Series. Figures 87, 88, 89, and 90 show comparisons of the mousse/oil content of the water effluent stream, free water content of the mousse/oil effluent stream, and water removal hydrocarbon removal efficiency between the Mousse and Crude Oil Test Series. Only data from the 100% system capacity tests of the Crude Oil Test Series are included in the comparison. The figures show better overall performance during the Mousse Test Series. The trend of increased influent mousse or oil content producing lower water removal is generally the same between both series of tests, however.

12.5 Mousse With Emulsion Breaker Test Series

12.5.1 Test Plan Modifications. Test #2 was intended to be a 5% mousse influent test, but later analysis indicated an influent mousse content of 25% Difficulty in reading the mousse to free water ratio at low mousse contents with the effect of residual emulsion breaker in the stream, along with flow meter problems in the mousse supply line at low flow rates were probably the cause of the error.

Test #5 (100% mousse) in this series had to be cancelled due to a shortage of mousse near the end of the series.

This test series was conducted over two days - tests #1 through #3 were conducted the first day, and test #4 was completed the following day.

12.5.2 Specific Test Conditions. The mousse viscosity before mixing with free water or emulsion breaker averaged 22,517 cP (at shear rate = 10 sec^{-1}, 15° C), for this test series. This is about 5000 cP lower than for the Mousse Test Series, where viscosity averaged about 27,500 cP (shear rate = 10 sec^{-1}, 15° C). Emulsified water volume averaged roughly 52% for this test series, compared to an average of 60% for the Mousse Test Series, explaining the reduced viscosity. Interfacial tension was measured at 25.2 dynes/cm for a sample of this mousse, which is comparable to

results for the Mousse Test Series influent. The average viscosity of the mousse in the influent stream after the addition of emulsion breaker was 16,800 cP at shear rate = 10 sec^{-1}, 13° C.

The emulsion breaker Exxon Breaxit 7877 was added at a rate of 675 ml/min, corresponding to a dosage of 660 ppm to total flow for tests #2 and #3 (25% and 26% mousse influent, respectively), for this test series. The emulsion breaker addition data for test #3 is suspect, however, and may explain the slight difference in performance between these two tests where all other conditions were essentially the same. The emulsion breaker addition rate for test #4 averaged only 440 ml/min, corresponding to a dosage of 440 ppm to total flow. Although the readings on the peristaltic pump indicated a similar flow rate as for the other tests, the pump may have required re-calibration for the higher line pressures associated with the 52% mousse influent in test #4. This may have resulted in the lower dosage rate for this test.

12.5.3 Test Results. A summary of the conditions and test results for the Mousse With Emulsion Breaker Test Series on the Vortoil system is shown in Table 17. Mousse property data for samples from the mousse supply line, from samples after mixing with free water and emulsion breaker in the influent line, and from the mousse/oil effluent stream after separation are shown in Table 18.

12.5.3.1 Mass Balance Analysis. Figures 91a through 91d illustrate the fluid mass balance between influent and effluents for each test of this series. These figures again illustrate the effectiveness of the Vortoil system in bulk separation of mousse and oil from free water for all influent mixtures. These figures show no significant change in the total volume of emulsion present before and after separation.

12.5.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 92 shows the mousse/oil content of the water effluent stream and the free water content of the mousse/oil effluent stream as a function of influent mousse content. Figure 93 shows water removal efficiency and hydrocarbon removal efficiency plotted against influent mousse content. Again, the Vortoil system performed well with efficiencies consistently in the 90th percentile or better for all conditions although hydrocarbon removal and water removal were negatively affected by the presence of emulsion breaker when compared to results from the Mousse Test Series. Hydrocarbon removal efficiency was observed to gradually improve with increasing mousse content in the influent, and water removal efficiency gradually decreased as in previous test series. There was a 2% drop in water removal efficiency between tests #2 and #3, although the influent conditions were essentially the same. As noted earlier, the emulsion breaker addition rate data was suspect for test #3, and this may have had some impact on water removal performance.

12.5.3.3 Impact of Separation on Emulsified Water Content. Figure 94 shows the changes in emulsified water content between the influent and mousse/oil effluent

for this test series. Emulsified water content decreased significantly in both tests #2 and #3 (25% and 26% influent mousse), but the 52% mousse influent test (test #4) results show about a 30% increase in emulsified water content.

12.5.3.4 Impact of Emulsion Breaker on Viscosity. Figure 95 shows a consistent and substantial decrease in viscosity after the addition of Breaxit 7877 and mixing, and again after separation. After the addition and mixing of the emulsion breaker, viscosity dropped an average of 5700 cP (at shear rate = 10 sec^{-1}, 14° C average), or 25%. The total drop after separation was 19,100 cP (shear rate = 10 sec^{-1}, 14° C average), or 85% of the viscosity of the mousse prior to the addition of the Breaxit 7877.

12.5.3.5 Impact of Separation on Mean Oil Droplet Size. Because the oil content of the water effluent stream was measurable in large quantities for each test in this series and was not dispersed in the free water, a comparison of droplet size is not meaningful for these tests. As observed during the Alfa-Laval Mousse With Emulsion Breaker Test Series, the emulsion breaker reduces the mean oil droplet size in the influent greatly.

12.5.3.6 Influent and Effluent Line Pressure. Figure 96 shows influent and water effluent line pressures plotted against time for this test series. As observed during the previous test series, influent line pressure increased when effluent water line pressure decreased, caused by the system recycling part of the water effluent stream back to the surge tank. In contrast with the results from the two previous test series on the Vortoil system, water effluent pressure did not drop as low for the higher influent mousse content tests in the series, but this is most likely due to the higher flow rates for tests #3 and #4 of this series. More free water available as a result of the effect of the emulsion breaker would reduce the amount of water effluent that had to be recycled back to the surge tank, which also may impact water effluent pressure. However, the titration results of the mousse/oil samples, showing emulsified water content, do not support this explanation.

12.5.3.7 Comparison to Mousse Test Series Results. Figures 97, 98, 99, and 100 show comparisons of the mousse/oil content of the water effluent stream, free water content of the mousse/oil effluent stream, and water removal and purification efficiencies for the Mousse and Mousse With Emulsion Breaker Test Series. Figure 99 shows a slightly better water removal efficiency for the Mousse Test Series, although the difference is small. The data shows a trend of decreasing water removal efficiency with increased influent mousse content, also observed in previous tests.

Figures 97 and 98 show a significant degradation in hydrocarbon removal performance with the addition of emulsion breaker. Mousse/oil content in the water effluent line for the Mousse Test Series was consistently below the background level from the 100% water test, compared to 2 to 3 percent for the Mousse With Emulsion Breaker Test Series. The degradation in water effluent quality with the addition of a

chemical emulsion breaker is most likely caused by the chemical dispersing very small droplets of oil in the water which are more difficult to remove. Another possible explanation offered by Conoco was that the water breaking out of the mousse was creating a higher effluent water rate than could be effectively handled by the system. However, similar observations were noted for the same test series on other separators, and the data showing change in emulsified water content does not support this theory. Therefore, the degradation in performance is most likely attributed to the impact on the chemical on the dispersion of oil in water, not due to limitations of the Vortoil system.

Figures 101 and 102 show the change in emulsified water volume data for the two test series, presented side by side for easier comparison. There are two notable differences between the two sets of tests. First, the Mousse With Emulsion Breaker Test Series data shows significant decreases in emulsified water volume for tests where the influent mousse content was near 25%. In comparison, the Mousse Test Series results show no significant change in emulsified water volume. Second, for mousse influent content at 50% or greater, the Mousse Test Series data showed a small drop in emulsified water volume where the Mousse With Emulsion Breaker Test Series results showed a 30% increase in emulsified water content for the 52% mousse influent test. Unfortunately, no comparison of performance with 100% mousse influent is possible since this test of the Mouse With Emulsion Breaker Test Series had to be cancelled due to a shortage of mousse.

The most striking benefit of the addition of the emulsion breaker Breaxit 7877 is the drop in viscosity illustrated in Figure 95, and discussed in paragraph 12.5.3.4.

12.6 Debris Test Series

12.6.1 Test Plan Modification. None for this test series.

12.6.2 Specific Test Conditions. The debris mixture was added at a rate of 0.25 lb/minute. The target influent oil ratio for this test series was 25%, but lab sample data and a mass balance analysis indicated a higher oil content. The influent ratios determined from the 1 liter laboratory samples were selected as the most reliable data for influent oil/water ratios for this test series. The average viscosity of the oil used for this test series was approximately 1110 cP (shear rate = 10 sec^{-1}, 18° C), with a difference in specific gravity from water of 0.103. The interfacial tension measured between a sample of this oil and distilled water was 21.5 dynes/cm.

12.6.3 Test Results. A summary of the conditions and test results for the Debris Test Series on the Vortoil system is shown in Table 19. Specific test results are discussed below.

12.6.3.1 Impact of Debris on System Operation. Operation of the Vortoil system was limited by the pressure differential across the simplex strainer in the system. The strainer manufacturer's maximum recommended pressure differential

across the strainer is 20 psi. During the debris addition portion of the test series, the pressure differential stayed low for the first 27 minutes, and then gradually increased. The differential pressure across this strainer is plotted against time in Figure 103. The differential pressure data was not recorded electronically, but was periodically noted by the Vortoil operator. After 43 minutes the differential pressure had reached 18 psi. At this time, the test was stopped due to problems with the testing equipment. When the test was started again, initially with 100% before bringing in the oil and debris influent streams, the reading was 18 psi. When the oil was added, the pressure increased to 20 psi, and the test was stopped. Vortoil personnel said that the test could continue, but with the possibility of damage to the strainer.

It also must be noted that the day following this test, when modifying the facility set-up for the next separator, a large amount of oily debris was found in some of the piping well upstream of the separator. The total amount of oily debris was estimated at approximately 10 gallons, although the dry weight of the debris content was not measured. This implies that the separator probably would have reached a limiting pressure sooner, if the full amount of debris added to the influent had made it to the separator.

12.6.3.2 Mass Balance Analysis. Figures 104a through 104f illustrate the fluid mass balance between influent and effluents for all tests and test periods of this series. Figure 104g shows the average performance over all of test #2. While these figures still show good overall bulk separation of the two fluids, a definite degradation in performance can be observed when compared to previous tests without debris.

12.6.3.3 Water Removal and Hydrocarbon Removal Performance. Figure 105 shows the oil content of the water effluent stream and the free water content of the oil effluent stream plotted as a function of time for this test series. Figure 106 shows water removal and purification efficiencies plotted against time. Both water removal efficiency and hydrocarbon removal efficiency were low at the start of debris addition and improved considerably over the next 15 minutes. However, both efficiencies dropped considerably after 20 minutes of debris addition, and then improved again until the test was stopped after 43 minutes.

12.6.3.4 Impact of Separation on Emulsified Water Content. Figure 107 shows moderate to substantial increases in the emulsified water content between the influent and oil effluent stream for each period of test #2. In comparing the data shown in Figures 105, 106 and 107, water removal efficiency and hydrocarbon removal efficiency dropped and emulsification increased at about 20 minutes of debris addition, after which efficiency and emulsification were more typical of previous tests. This seems to indicate that some event, perhaps a temporary debris clogging, occurred within the system at that time, after which the separator recovered and began to improve water removal and hydrocarbon removal. Because similar performance was observed at the beginning of the tests, a similar event may have occurred at this time as well.

12.6.3.5 Impact of Separation on Mean Oil Droplet Size. Because the oil content of the water effluent stream was measurable in large quantities for each test in this series and was not dispersed in the free water, a comparison of droplet size is not meaningful for these tests.

12.6.3.6 Influent and Effluent Line Pressure. Figure 108 shows influent and water effluent line pressures plotted against time for the Debris Test Series, along with a plot of the differential pressure across the simplex strainer for the test series. The pressure plot for the strainer was discussed earlier in this test section, but is included here for comparison to the other line pressures. The figure shows the same pattern seen in the previous tests of increased influent line pressure with drops in the effluent water line pressure, and some moderate fluctuations in pressure, which all are presumably caused by changes in the volume of hydrocyclone water effluent recycled to the surge tank, on command from the level control device. There appears to be no impact to influent of water effluent line pressures due to debris, indicating that no clogging occurred within the surge tank or in the water effluent stream. In contrast, the differential pressure across the simplex trainer upstream of the hydrocyclones gradually increases with time, indicating that the strainer was gradually becoming clogged with debris.

12.6.3.7 Comparison to Crude Oil, Mousse, and Mousse With Emulsion Breaker Test Series Results. Because the Crude Oil Test Series for this separator did not contain a test with an actual oil influent ratio near the 56% average oil influent ratio in the Debris Test Series, no direct comparison of performance can be made. However, the Mousse and Mouse With Emulsion Breaker Test Series had 61% and 52% mousse influent ratios, respectively. Figure 109 shows a comparison of oil content of the water effluent stream, free water content of the oil effluent stream, and water removal purification efficiencies for all four test series, using the average values for test #2 for the Debris Test Series since there was not a strong relationship with the cumulative amount of time of debris addition. While this figure indicates that either the separator performs quite differently with crude oil and mousse influents, or that debris had a significant impact on the performance of the system, independent of the limitation due to pressure differentials across the strainers. Conoco Specialty Product's personnel believe that the poorer performance during the Debris Test Series is a result of the higher oil content in the influent and not the result of the debris. However, the system performed quite well at a mousse influent ratio of 62% during the Mousse Test Series, which is a content higher than that of crude oil in the Debris Test Series, indicating that the system may perform better with influents contained emulsions compared to un-emulsified oils.

12.7 Observations on Operability, Reliability, Maintenance, Safety and Transportation

12.7.1 Operability. The Vortoil system has low operability requirements, once set up and running. During the tests, Conoco had an engineer manning the hydraulic controls

for the feed pump, but this would not be required during actual operations. Since these were the first tests of the prototype system with any fluid besides 100% water, they kept a person stationed at the control to stop the system if required for any reason. During the entire test period, there was never a need to immediately shut off the system because of danger to the equipment or personnel. The only requirement for shutting down the system came at the conclusion of the Debris Test Series when the differential pressure across the simplex strainer in the system reached the design limit. Proposed modifications to the system will eliminate the need for the system to be shut down to clean the strainer.

The set-up of the Vortoil system required knowledge and skills for setting the level control device at the interface between the free water and the oil/mousse components in the surge tank at the start of each test series. After the level was established, no other monitoring or operational requirements were required to run the system. Establishing the level control interface point usually took from one to ten minutes.

12.7.2 Reliability. During the course of the program, tests were delayed twice due to problems with the system. At the start of the test program on the Vortoil, a severe leak from a gasket in the body flanges of one of the hydrocyclone vessels was observed. The gasket had to be replaced, which required disassembling the hydrocyclone vessel itself to some degree. The leak was attributed to improper materials selected for the gasket. Replacement of the gasket took approximately 6½ hours, including preparation of a new gasket. The revised design proposed by Conoco includes redesign of the hydrocyclone vessel eliminating the body flanges altogether, which will eliminate the source of the leaks.

Tests were delayed a second time due to problems with the level control system. It was later determined that the antenna on the system had become disconnected. Troubleshooting and correcting the problem took approximately 1½ hours.

The only other reliability concern was a constant small leak from the Desmi feed pump included in the system, both from the pump itself and from the discharge connection. These did not impact separator performance, and both of these sources of leaks have been eliminated in the revised design proposed by Conoco.

12.7.3 Maintenance. As described above, the gaskets in the hydrocyclone vessels had to be replaced, but this is not a normal maintenance function. No other maintenance requirements were observed during the test program.

12.7.4 Safety. No safety problems were observed with this system.

12.7.5 Transportability. The unit was easily transported by truck and moved with a forklift during the test program. The entire separation system, with the exception of an external hydraulic power source, is mounted in a single frame/skid assembly with built-in forklift slots.

12.8 Summary and Manufacturer's Input on Vortoil

12.8.1 Summary of Strengths and Weaknesses. The Vortoil Oilspill Separation System performed very well with respect to both water removal and hydrocarbon removal at influent crude oil ratios below about 50%. The system was not negatively impacted by the presence of mousse in the influent. On the contrary, the system performed better against influent emulsions than with crude oil, even when influent mousse ratios exceeded 50%. The separator was able to handle influents of either 100% water or 100% oil or mousse quite effectively, and was the only separator tested that demonstrated this capability. In addition, the system has a relatively low weight and weight to capacity ratio despite its large footprint. The performance of the Vortoil system was especially notable in light of the fact that these tests represented the first operation of the prototype system with an influent consisting of anything other than pure water.

The weaknesses of the system were the poor water quality results obtained when the crude oil influent ratio exceeded about 50%, a time-limited capability to handle debris (43 minutes of testing), and a tendency to increase the emulsified water content for the crude oil and water influents - sometimes showing a tenfold increase in emulsified water content. The system also showed reduced water removal capabilities when the influent was fed to the system at 50% capacity.

12.8.2 Manufacturer's Input. Based on the test results and observation made during the test program, Conoco Specialty Products Inc., has recommended the following modifications to the system and system operation to improve separation performance:

1) To improve water quality at the higher influent crude oil ratios, Conoco recommends that the controls on the Vortoil system be adjusted to provide better water quality at some expense to water removal. Prior to testing, the controls had been set for a balance of performance between water removal and hydrocarbon removal over the range of expected test conditions. Selecting the control settings to provide for better hydrocarbon removal performance prior to operation is an operational recommendation only, and does not involve any modifications to the system itself.

2) To improve separation performance, Conoco proposes adding diffusers to the inlet and recycle connections inside the system surge tank. This will reduce the velocity of these streams coming into the surge tank, that in turn result in mixing inside the tank. This mixing is believed to be responsible for higher than expected oil concentrations being fed to the hydrocyclones, which reduced separator performance for some of the tests with crude oil.

3) Conoco also plans to increase the diameter of the hydrocyclone oil outlet piping, which under high influent oil concentrations restricted the oil effluent. This

restriction forced more oil through the water effluent stream, negatively impacting water effluent quality.

4) The simplex strainer between the surge tank and hydrocyclones will be replaced with a duplex strainer, allowing continuous operation with no shutdown required for strainer cleaning. This feature would have enabled the Vortoil system to complete the Debris Test Series without having to stop to clean the simplex strainer. In addition, the duplex strainer at the inlet surge tank will be removed. The primary reason for including the inlet strainer was to prevent the surge tank from becoming clogged, and Conoco now believes that any debris that would be fed to the system will have been macerated to a small enough size that it will not plug the surge tank.

5) The maximum allowable working pressure of the surge tank will be increased, and a "re-settable" pressure relief device will replace the rupture disk to allow oil discharge under higher back pressure conditions. The oil outlet pressure control valve also will be eliminated, and a siphon breaker will be installed on the oil effluent line to prevent a vacuum from developing inside the surge tank.

6) The Desmi pump included in the system, which leaked through its case during the tests, will be upgraded to the latest version, that has been redesigned to eliminate the leak. The Cam-Lok pump discharge connection will be replaced with a flanged connection to eliminate leaks that occurred when the original connection was pulled off-square by outlet piping.

7) The hydrocyclone vessels have been redesigned to eliminate the body flanges that were the source of gasket leaks during the tests. The redesign of the vessels also will result in a significantly lower weight.

8) The structural skid for the production model of the Vortoil system will be made of either fiberglass or aluminum to reduce system weight. Plastics will be used in the system, where appropriate, and the system layout will be condensed to further reduce sized and weight. The revised system is expected to weigh well below 6,000 lbs and have a skid footprint less than 70 ft^2.

13.0 INTR-SEPTOR 250 SYSTEM CHARACTERISTICS AND TEST RESULTS

13.1 System Information

13.1.1 System Description and Principle of Operation. International Separation Technology's Intr-Septor 250 centrifugal separator was the fourth separator tested in the program. A photograph of the system is shown in Figure 110. The influent is externally pumped to the top of the separator and feeds into the "mixing chamber" of

the separator, which is packed with plastic coalescing media to start the separation process and aid in the mixing of any emulsion breaking chemical used. A tapered rotor accelerates the fluid to approximately 500 g's, which produces the separation. Effluent weirs direct the oil and water effluents through lines leaving the system through the base of the separator. The system delivered to the test site was driven with a 20 hp motor, mounted on the same base as the separator. The motor also can be seen in Figure 110. During initial calibration tests, the 20 hp motor was insufficient to operate the system, and a 40 hp motor was substituted for the actual tests.

13.1.2 Dimensions, Capacity, Power Requirements and Special Logistics Characteristics. The Intr-Septor 250 is a compact system mounted on a single base as shown in Figure 110, and was easily transported by forklift. System dimensions, weight, and power requirements are shown in Table 20. The manufacturer's rated capacity for this prototype unit was 250 gpm, but even with the 40 hp motor the maximum sustained flow rate recorded during the tests was 155 gpm. The capacity limitations were noted during early calibration runs, and it was decided to set the target capacity for all actual tests on the separator at 125 gpm. A second model has been designed since the completion of the tests, incorporating several improvements for improved performance, including increased capacity. These improvements are discussed later in this report. The total system weight for this separator is 5404 pounds with the 20 hp motor, including a 3000 pound generator required for power. The separator itself weighed only 2404 before the 20 hp motor was replaced with the 40 hp unit. Separator weight was not measured again after the replacement was made. The weight to capacity ratio for this system, using 155 gpm capacity and the system weight with the 20 hp motor, is 35 lbs/gpm.

13.2 Test Set-Up for Intr-Septor 250. A schematic layout of the test set-up for all Intr-Septor test series is shown in Figure 111. Two 400 gallon intermediary tanks were needed to capture the water and oil effluent streams before pumping to the reclaimed oil and water effluent tanks. The separator was designed to operate with no back pressure on either effluent line, requiring the use of the intermediary tanks for these tests.

The standard design for the Intr-Septor 250 includes effluent weirs set for maximum separation efficiency for oils with specific gravities in the range from 0.82 to 0.92. For this series of tests, weirs that were more appropriate to cover the range from 0.90 to 0.98 were used to better match the anticipated test conditions.

13.3 Crude Oil Test Series

13.3.1 Test Plan Modifications. The Intr-Septor 250 was tested using the modified Crude Oil Test Series plan, incorporating both sea motion and reduced capacity tests.

13.3.2 Specific Test Conditions. The average crude oil viscosity for this test series averaged 1242 cP (shear rate = 10 sec^{-1}, 17 ° C), and the interfacial tension between a sample of this oil and distilled water was 11.9 dynes/cm.

Visual determinations of influent oil/water ratios for this test series matched very poorly with results of the mass balance analyses conducted using effluent stream data, which is believed the be the most reliable data for this test series, and was used to calculate the actual influent oil ratio. This resulted in the Intr-Septor system being tested at much higher oil/water ratios than intended. Test #5 (50% target oil influent ratio) was aborted because the separator was drawing too high of a load from the generator, and the separator was shut off by Intr-Septor personnel to protect the unit. Because the influent graduated cylinder readings were approximately 50% when the separator was turned off, and the readings for all other tests of this series were consistently low, the actual influent oil content during the attempt at test #5 may have been 75% or higher. Test #7 (100% oil) was cancelled when it was determined that the separator was unable to handle this lower oil influent ratios.

In addition to the problems with determining influent oil content for these tests, extremely inaccurate flow meter readings during the reduced capacity test (test #3) resulted in this test being conducted at no lower capacity than other tests in this series.

Test #6 was the simulated sea motion test, with motion set at ± 15° from horizontal at a period of 7.25 seconds. The target oil influent content for this test was modified to 25% as the separator was unable to handle what we thought to be 50% oil during the preparation for test #5 (discussed above). The mass balance analysis indicates that the actual influent oil ratio for the sea motion test was 59%.

13.3.3 Test Results. A summary of the conditions and test results for the modified Crude Oil Test Series on the Intr-Septor 250 is shown in Table 21. Specific test results are discussed below.

13.3.3.1 Mass Balance Analysis. Figures 112a through 112e illustrate the fluid mass balance between influent and effluents for each test of this series. These figures show that independent of the influent and effluent oil and water make up, on average 73% of the total flow leaves the system through the oil effluent line, and 27% through the water effluent line.

13.3.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 113 shows the oil content of the water effluent stream and the free water content of the oil effluent stream plotted against influent oil content for the stationary tests of this series. Figure 114 shows both water removal and purification efficiency as a function of the influent oil ratio for the same tests. Overall, the separator performed relatively well with regard to hydrocarbon removal, with efficiencies ranging from 86% to 96% (92% average), but was considerably poorer at removing water from the influent. Independent of the influent oil content, water effluent oil content dropped to 2%-3%. Water removal efficiency ranged from 30% to 98%, averaging 58%. Both

hydrocarbon removal and water removal efficiency were observed to improve as oil content of the influent was increased.

The separator was unable to handle 100% water influent effectively, and was unable to take 100% oil at all. During the 100% water influent test (test #1), the separator sent 32% of the total flow out the oil effluent line. The separator was not tested at 100% oil as it had been determined earlier that the separator was over capacity at lower oil/water influent ratios.

13.3.3.3 Impact of Separation on Emulsified Water Content. Figure 115 shows the change in emulsified water content between the influent and oil effluent stream for each test of this series. Test #2 (21% oil influent) shows a small drop and test #5 (61% oil) a moderate increase. A five-fold increase in emulsified water volume was observed during the 65% and 59% influent oil tests.

13.3.3.4 Impact of Separation on Mean Oil Droplet Size. Because the oil content of the water effluent stream was measurable in large quantities for each test in this series and was not dispersed in the free water, a comparison of droplet size is not meaningful for these tests.

13.3.3.5 Influent Line Pressure. Figure 116 shows influent line pressure plotted against time for this test series. Influent line pressure was relatively consistent throughout the tests, ranging from 7.7 to 9.2 psi, and was very consistent during each test. Because both effluent streams emptied into the open intermediary tanks before transfer to oil and water effluent tanks, the influent line pressure also represents the total pressure drop across the separator.

13.3.3.6 Impact of Sea Motion. Figure 117 illustrates that simulated sea motion (test #6) had virtually no impact on hydrocarbon removal efficiency. The figure also indicates a small drop in water removal efficiency, but the change is small enough that it may be the result of inaccuracies in the data. For tests #3, #4 and #5, the effluent oil stream data was difficult to read and did not match well with a mass balance analysis. The oil/water ratio determined from the five minute laboratory samples was used for oil content in the oil effluent stream data to calculate the actual influent ratios, which in turn was used to calculate water removal efficiency. The use of this data, and the inaccuracies that were prevalent throughout this particular series, make it impossible to determine if the drop shown for water removal efficiency was actually due to the sea motion or merely a consequence of the data quality. Because of the high "g" forces imparted by the separator, it is unlikely that sea motion would have a significant impact on performance.

13.4 Mousse Test Series

13.4.1 Test Plan Modifications. Test #5 (100% mousse) was cancelled due to problems with the test facility equipment. It was noted, however, that the Intr-Septor

was able to handle 100% mousse for the short time before the test equipment failed. Unfortunately, because the test had to be aborted, it could not be verified that the Intr-Septor as configured for these tests would be able to handle 100% mousse for more than one or two minutes.

13.4.2 Specific Test Conditions. The viscosity of the mousse in the mousse portion of the influent mixture averaged 27,567 cP (shear rate = 10 sec^{-1}, 16° C), with an emulsified water volume of 64%. The interfacial tension between distilled water and a sample of mousse taken from the mousse supply line measured 43.5 dynes/cm.

13.4.3 Test Results. A summary of the conditions and test results for the Mousse Test Series on the Intr-Septor system is shown in Table 22. Mousse property data from the mousse supply line, from the influent mixture line, and from the mousse/oil effluent line after separation are shown in Table 23. Specific test results are discussed below.

13.4.3.1 Mass Balance Analysis. Figures 118a through 118d illustrate the fluid mass balance between influent and effluents for each test of this series. Similar to the results from the modified Crude Oil Test Series, these figures show that the ratio between mousse/oil effluent and water effluent stream volumes does not change with changes in the influent mousse to free water ratios. For this series, the mousse/oil effluent stream comprised 56% of the total flow on average, compared to 44% for the water effluent stream. The average total flow in the mousse/oil effluent stream is lower than that observed during the Crude Oil Test Series, resulting in improved water removal efficiency for the Mousse Test Series. This is discussed in more detail in a later section comparing the results of the two test series.

Figure 118b, which shows the mass balance for test #2 (6% influent mousse), indicates a nearly equal amount of the mousse leaving the system through each effluent line. Figures 118c and 118d, however, show that the separator's ability to separate improves with increased influent mousse content. These results indicate that separation performance may be hindered by the hydraulic design of the effluent routes.

13.4.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 119 shows the mousse/oil content of the water effluent stream and the free water content of the mousse/oil effluent stream plotted against the influent mousse content for this test series. Figure 120 shows both water removal efficiency and hydrocarbon removal efficiency as a function of the influent mousse ratio. Hydrocarbon removal was poor for these tests, with the mousse/oil content reduced by only about one half between the influent and the water effluent. Hydrocarbon removal efficiency ranged from 46 to 51% throughout the tests, and was relatively unaffected by the mousse content of the influent. Water removal efficiency ranged from 38 to 71%, with a significant increase in performance with increased mousse content of the influent.

13.4.3.3 Impact of Separation on Emulsified Water Content. Figure 121 shows that there was no significant change in emulsified water content between the influent and mousse/oil effluent stream tests #3 and #4 of this series (26% and 52% mousse, respectively). Mousse/oil samples for test #2 (6% mousse influent) were too small to test for emulsified water volume.

13.4.3.4 Impact of Separation on Mean Oil Droplet Size. Because the oil content of the water effluent stream was measurable in large quantities for each test in this series and was not dispersed in the free water, a comparison of droplet size is not meaningful for these tests.

13.4.3.5 Influent Line pressure. Figure 122 shows the influent line pressure for all tests of this series, and illustrates that the influent line pressure increased with the mousse content of the influent. Pressures ranged from an average of 8.9 psi for test #2 (6% mousse) to 19.6 psi for test #4 (52% mousse). The figure also shows a sharp rise after the conclusion of test #4, to a value of 32.6 psi. This corresponds to the short time that 100% mousse was fed to the separator before the test was cancelled due to problems with the test facility equipment.

13.4.3.6 Comparison to Crude Oil Test Series Results. Figures 123, 124, 125, and 126 show comparisons of the mousse/oil content of the water effluent stream, free water content of the mousse/oil effluent stream, and water removal and purification efficiencies between the Crude Oil Test and the Mousse Test Series for the Intr-Septor. Figure 125 shows a moderate improvement in water removal efficiency for the Mousse Test Series compared to the Crude Oil Test Series. This also could be seen in the mass balance charts (Figures 118a through 118d), where the average total proportion of flow out the mousse/oil effluent line was smaller during the Mousse Test Series than the Crude Oil Test Series. This may be the result of the higher viscosity mousse restricting the flow rate out the mousse/oil effluent line and causing a higher flow rate in the water effluent stream.

Figures 123 and 126 show that the separator's ability to purify water is greatly impacted by the change from crude oil to mousse. During the Crude Oil Test Series, the oil content of the water effluent was reduced to 2-3%, independent of the influent oil ratio. In contrast, the mousse/oil content of the effluent water stream increased with increased mousse content in the influent during the Mousse Test Series. The mousse/oil content was effectively reduced by only one half between the influent and effluent water stream for these tests.

13.5 Mousse With Emulsion Breaker Test Series

13.5.1 Test Plan Modifications. None for this test.

13.5.2 Specific Test Conditions. The viscosity of the mousse prior to mixing with the emulsion breaker or free water averaged 32,113 cP at shear rate = 10 sec^{-1}, 17° C.

The viscosity of the mousse portion of the influent after the addition of emulsion breaker) averaged 9,923 cP at shear rate = 10 sec^{-1}, 16° C. A significant drop in the viscosity of the mousse portion of the mixed influent was observed over the course of the test period. Viscosity was 17,050 cP (shear rate = 10 sec^{-1}, 16° C), during test #3 (39% mousse), and dropped to only 229 cP (shear rate = 10 sec^{-1}, 16° C) in test #5 (100% mousse). Because the influent mousse samples (before the addition of the emulsion breaker) indicated no significant change in viscosity over the same period, the drop in viscosity is attributed solely to the effect of the emulsion breaker. The interfacial tension between distilled water and a sample of mousse taken from the mousse supply line before the addition of emulsion breaker was 44.1 dynes/cm. This is comparable to the value obtained for a sample from the Mousse Test Series.

The emulsion breaker EXXON Breaxit 7877 was added at a rate of 290 ml/min during all tests, corresponding to an average dosage of 540 ppm Breaxit 7877 of the total influent flow for each test.

During preparation for the 100% mousse test, the separator was unable to handle 100% mousse, even at reduced flow rates. The test was successfully started later by feeding water to the separator, starting injection of the emulsion breaker, and then slowly introducing the mousse influent while gradually reducing the water influent to zero. While successful for nearly the entire 100% mousse test, the test was aborted after nine minutes due to limitations of the separator, which began to draw too much amperage from the generator at about this time. During this test, the flow rate had been gradually reduced to overcome high line pressures in the test set-up. Despite the decrease in flow rate, the average rate during this test was calculated at 172 gpm - much higher than indicated by the flow meters, and well over the target 125 gpm flow rate for this separator. If the test had been conducted nearer to the 125 gpm target flow rate, the separator may have been able to complete the entire 10 minute test with 100% mousse.

13.5.3 Test Results. A summary of the conditions and test results for the Mousse With Emulsion Breaker Test Series on the Intr-Septor 250 are shown in Table 24. Mousse property data from the mousse supply line (before the addition of emulsion breaker), from the influent mixture line (after the addition of emulsion breaker and mixing with free water), and from the mousse/oil effluent line after separation are shown in Table 25.

13.5.3.1 Mass Balance Analysis. Figures 127a through 127e illustrate the fluid mass balance between influent and effluents for each test in the series. As in the previous tests, these results show that the ratio between mousse/oil effluent and water effluent stream volumes does not change with changes in the influent mousse or oil content for this separator. For this test series, the mousse/oil effluent stream comprises 65% of the total flow on average, with 35% in the water effluent stream. Figure 127b shows a higher volume of mousse in the combined effluents than in the influent stream. This could be attributed to a small increase in the emulsified water content of the mousse after separation for these tests. Figures 127c and 127d show

slight demulsification taking place, with roughly 3% and 8% of the mousse, respectively, demulsified after separation for these tests. These two figures also show that the separator improves in its ability to separate as the mousse content of the influent increases. Figure 127e shows that for the 100% mousse influent test significant demulsification was occurring, with approximately 30% of the total influent emerged from the separator as free water, and nearly all in the water effluent stream. During the test, the effect of the emulsion breaker was visually obvious. Distinctly black (demulsified) oil and chocolate brown mousse could be seen clearly in the mousse/oil effluent stream.

13.5.3.2 Water Removal and Hydrocarbon Removal Performance. Figure 128 shows the mousse/oil content of the water effluent stream and the free water content of the mousse/oil effluent stream plotted against the influent mousse content for this test series. Figure 129 shows both water removal efficiency and hydrocarbon removal efficiency as a function of the influent mousse content. Water removal efficiency ranged from 38% to 52% for the tests that included some free water in the influent mixture. Water removal efficiency for the 100% mousse test (test #5) was 95%. The graph shows a gradual improvement in water removal efficiency with increasing mousse influent content, consistent with previous tests on this separator.

Hydrocarbon removal efficiency ranged from 75% to 98% for the tests containing some free water in the influent, and was 74% for 100% mousse influent. Hydrocarbon removal was significantly better in these tests, with mousse/oil content of the water effluent down to 1% for all tests except the 100% mousse influent test.

Overall, separator performance was greatly improved by the addition of the emulsion breaker.

13.5.3.3 Impact of Separation on Emulsified Water Content. Figure 130 shows no consistent impact of emulsion breaker on the emulsified water content of the mousse for these tests, even during the 100% influent mousse test (test #5), where significant demulsification was taking place. Even in this test, the mousse remaining after separation had roughly the same emulsified water content as that of the influent mousse prior to the addition of the emulsion breaker.

13.5.3.4 Impact of Emulsion Breaker on Viscosity. Figure 131 shows dramatic impacts to viscosity resulting from the addition of the emulsion breaker for all tests in this series. On average, viscosity dropped about 23,000 cP (at shear rate = 10 sec^{-1}, 16° C average) after addition and mixing of the emulsion breaker Breaxit 7877. This drop is equivalent to 71% of the original viscosity. After separation, viscosity was further reduced for a total average reduction of 30,000 cP (at shear rate = 10 sec^{-1}, 16° C average), or 94% of original viscosity before addition of the chemical. Comparing these results to Figure 130, showing the change in emulsified water content before and after separation, it appears that the drop in viscosity is not due to a lower emulsified water content for the mousse remaining after separation.

13.5.3.5 Impact of Separation on Mean Oil Droplet Size. Because the oil content of the water effluent stream was measurable in large quantities for each test in this series and was not dispersed in the free water, a comparison of droplet size is not meaningful for these tests.

13.5.3.6 Influent Line Pressure. Figure 132 shows influent and effluent line pressures for all tests of this series, again showing an increase in influent line pressure with increased influent mousse content. For this series, the start of each test (except for the 100% water and 100% mousse tests) also was marked with a slight peak in pressure, with pressure very gradually decreasing over the duration of the series. This may be the result of the emulsion breaker taking a few minutes to have full effect on the viscosity of the mousse.

13.5.3.7 Comparison to Mousse Test Series Results. The average effluent flow rates for this test series, calculated as percent of total flow are in between those calculated for the Crude Oil Test and the Mousse Test Series, and may reflect the effect that viscosity has on the mousse/oil effluent stream. To illustrate the impact that viscosity has on mousse/oil effluent stream flow rate (and hence water removal efficiency for this separator), Figure 133 shows average mousse/oil effluent stream flow rate as percent of total flow plotted against average influent mousse viscosity for the three test series.

Figures 134, 135, 136, and 137 show comparisons of the mousse/oil content of the water effluent stream, free water content of the mousse/oil effluent stream, and water removal and purification efficiencies for the Mousse and Mousse With Emulsion Breaker Test Series. Water removal efficiency was negatively impacted by the addition of the emulsion breaker, but can be explained by the impact that decreasing the viscosity has on mousse/oil effluent stream flow, discussed in the preceding paragraph. In both instances, water removal efficiency improves with increased influent mousse content. Figure 137 shows a 100% increase in hydrocarbon removal efficiency for the Mousse With Emulsion Breaker Test Series over the Mousse Test Series - the mousse/oil content in the water effluent stream for this test series was lower than any other tests on the Intr-Septor, at only 1% mousse/oil for all tests except those with 100% mousse influent. Figures 138 and 139 are the emulsified water volume charts from the Mousse and Mousse with Emulsion Breaker Test Series presented together for comparison. These show no consistent or significant impact to emulsified water volume due to the addition of emulsion breaker in these tests.

13.6 Debris Test Series

13.6.1 Test Plan Modifications. None for this test.

13.6.2 Specific Test Conditions. The viscosity of the crude oil used for this test series averaged 514 cP (shear rate = 10 sec^{-1}, 20° C), and the interfacial tension between a sample of the oil and distilled water was 19.1 dynes/cm. The debris

mixture was added at a rate of 0.125 lb/minute over the entire 45 minute test #2. The target influent oil ratio for this test was 25%, but actual influent oil content was determined to average 51% over test #2, from the mass balance analysis of effluent stream data.

13.6.3 Test Results. A summary of the conditions and test results for the Debris Test Series are shown in Table 26. Specific results are discussed below.

13.6.3.1 Impact of Debris on System Operation. The addition of debris to the influent had no impact on system operation, with the exception of a very slight increase in influent line pressure over time (10.9 to 12.5 psi over 45 minutes), as illustrated in Figure 140. Average influent line pressure was slightly higher for the Debris Test Series (by about 2 psi) than for the Crude Oil Test Series at similar oil influent ratios, but there also was a comparable increase between the two series for the 100% water test. This indicates that the reason for the overall increase in pressure between the two test series was unrelated to the addition of debris.

The gradual increase in influent line pressure observed during the debris addition portion of this series may indicate a limit to the amount of time that debris could be handled by the separator without exceeding pressure limits if the pressure increase is the result of the system gradually becoming clogged with debris. Although the separator was not inspected internally by test personnel after the Debris Test Series because of time constraints, Intr-Septor personnel said that no debris was found inside the system when it was disassembled for cleaning after it was shipped back to their facility. At the conclusion of the Debris Test Series, however, 100% water was run through the system, which may have dislodged any debris remaining in the separator.

This separator was the only unit tested under debris conditions that was capable of completing the full 45 minute debris addition test.

13.6.3.2 Mass Balance Analysis. Figures 141a through 141f illustrate the fluid mass balance between influent and effluents for each test of this series. Although test #2 of this series was continuous, these figures show results in ten minute increments for test #2. Figure 141g shows the average performance over the entire test #2 period. During this test, the oil effluent stream comprised 69% of the total flow on average, with 31% in the water effluent stream. This relationship between effluent stream flow rates is closest to that observed during the Mousse With Emulsion Breaker Test Series.

13.6.3.3 Water Removal and Hydrocarbon Removal Performance. Figure 142 shows the oil content of the water effluent stream and the free water content of the oil effluent stream plotted as a function of time for the debris addition portion of this series. Figure 143 shows both water removal efficiency and hydrocarbon removal efficiency as a function of time over the same interval. The graphs shows a moderate increase in water removal performance over time that appears to level out again as test #2 comes to an end. Because neither flow rate nor influent oil content changed,

this is assumed to be due to the effect of debris on the system, as was the case for the slight increase in influent line pressure over time discussed earlier. The addition of debris could have the same effect on water removal efficiency that viscosity did, in that oily debris could restrict flow through the oil effluent route in the separator enough to provide lower resistance for water to leave the system through the water effluent line, increasing the water removal efficiency.

Hydrocarbon removal remained consistent over the entire 45 minute test period, with effluent water oil content between 5% and 7%, and hydrocarbon removal efficiency averaging 88%. Hydrocarbon removal performance did not appear to be impacted whatsoever by the cumulative addition of debris.

13.6.3.4 Impact of Separation on Emulsified Water Content. Figure 144 shows a very small increase in emulsified water content after separation throughout the Debris Test Series. The increases indicated in this figure are generally smaller than those recorded for the Crude Oil Test Series (Figure 115), indicating that the presence of debris has no adverse impact on emulsification with the Intr-Septor, and actually appears to help prevent it.

13.6.3.5 Impact of Separation on Mean Oil Droplet Size. Because the oil content of the water effluent stream was measurable in large quantities for each test in this series and was not dispersed in the free water, a comparison of droplet size is not meaningful for these tests.

13.6.3.6 Comparison to Crude Oil, Mousse and Mousse With Emulsion Breaker Test Series Results. Figure 145 shows a comparison of water removal and hydrocarbon removal efficiencies for all Intr-Septor tests at similar influent oil or mousse ratios. The figure indicates a slight decrease in both water removal and hydrocarbon removal efficiencies for the Debris Test Series results compared to some of the other test series, but the differences are not as great as those observed during the Mousse and Mousse With Emulsion Breaker Test Series. Overall, the impact of debris on Intr-Septor operation and performance was minimal over the 45 minute period.

13.7 Observations on Operability, Reliability, Maintenance, Safety, and Transportation

13.7.1 Operability. The system was extremely simple to set up and operate, requiring only the connection of influent and effluent lines and starting the motor with the push of a button.

13.7.2 Reliability. At the beginning of the test program for the Intr-Septor, several mechanical problems were observed. The primary problem was overloading the separator drive motor, which resulted in eventual replacement of the 20 hp motor with a 40 hp unit. In addition, the motor controller selected for the system was not intended for use in moist environments, and was negatively impacted by the weather

during the tests. The motor controller was wrapped in plastic to help prevent further damage. During the Crude Oil Test Series, the belt between the motor and drive shaft had be tightened.

International Separation Technology has made significant modifications to the Intr-Septor 250 design as a result of the experience gained during these tests on their prototype unit. Changes intended to overcome the problems described above are included in the new design.

13.7.3 Maintenance. The only maintenance requirement noted during the tests, in addition to the actions noted above, was a need to occasionally grease bearings. The manufacturer's proposed recommendations also with reduce or eliminate the need for this maintenance procedure during standard operations.

13.7.4 Safety. No safety problems were observed with operation of the unit.

13.7.5 Transportability. The unit was very easy to transport due to its compact size and low weight. Both the separator unit and motor were mounted on a single base, easily moved with a forklift.

13.8 Summary and Manufacturer's Input on Intr-Septor 250

13.8.1 Summary of Strengths and Weaknesses. The primary strength of the Intr-Septor 250 is the low weight and low weight to capacity ratio, even when calculated using the maximum sustained flow rate capacity of 155 gpm. Its ability to handle debris without any significant impact to performance or operation for a full 45 minute period also is a significant strength. Although the separator was not able to produce extremely clean water during any of the tests, mousse or oil content consistently dropped to 1% to 7% in the water effluent regardless of influent mousse or oil ratios in all tests except those in the Mousse Test Series. The separator performed best during the Mousse With Emulsion Breaker Test Series.

The primary weaknesses of the system are its inability to produce extremely clean water, relatively poor water removal efficiency, and poor reliability. Hydrocarbon removal was most affected during the Mousse Test Series, where the water effluent stream still contained approximately one half the fraction of the influent, independent of the influent ratio.

13.8.2 Manufacturer's Input. Based on the test results and their own observations during the tests, International Separation Technology has incorporated the following modifications into a re-design of the Intr-Septor 250 to improve performance and reliability.

1) The redesign incorporates changes to prevent overloads on the motor that were determined to be caused by oil forced in between the rotor and outer housing, creating a breaking effect on rotation.

2) The system has been reconfigured so that the motor is mounted directly on top of the housing, providing direct drive to the rotor shaft, which will significantly improve the efficiency of the power system. This modification eliminates the need for pulleys and belts, and should significantly improve reliability. Moving the motor to the top of the housing also eliminates the need for a base, which originally comprised 63% of the system weight. While other modifications will slightly increase component weight, a net reduction in system weight in excess of 1000 pounds is anticipated.

3) The shape of the rotor will be changed from a tapered cone to a cylinder, increasing "mixing chamber" volume and hence residence time for the influent. This should improve overall separation and hydrocarbon removal. The modification also simplifies and reduces the cost of fabrication.

4) The effluent stream routes have been redesigned to reduce restrictions of the water effluent stream that were determined to be responsible for the high volume of water in the oil effluent stream. The exit ports for both effluent streams also have been reconfigured to harness the existing centrifugal energy of the effluents to produce higher discharge velocities for both effluent streams.

5) The new design includes a port for injecting compressed air into the influent stream. This is expected to aid separation of oil products with specific gravities close to that of water by decreasing the density of the oil product with entrapped air. The design also includes another port for injecting emulsion breaking chemicals directly into the influent stream.

6) A secondary water weir that utilizes air pressure to adjust the oil/water interface is included in the new design. This will allow the separation process to be tuned during operation to optimize water removal and/or hydrocarbon removal by adjusting the interface to best suit the density difference between the oil and water in the tests.

7) Other improvements include fewer and better quality bearing seals, easier access to the interior of the separator for inspection, cleaning and maintenance, and relocation of the influent port to a more convenient spot.

14.0 SUMMARY AND COMPARISON OF TEST RESULTS

A summary of general performance results for all of the separators tested in this program is shown in Tables 27 through 32. Table 27 shows a comparison of system capacities and logistics characteristics. The five tables following include general performance data from the Crude Oil Test Series, impact from 100% water, oil, or mousse influents along with sea motion and reduced capacity, comparison of Mousse Test Series performance, Mousse With Emulsion Breaker Test Series, and the Debris

Test Series performance. Ranges and averages for water removal and hydrocarbon removal efficiencies are given for each test series, and the impacts from different influent conditions are noted. More detailed comparisons of specific separator characteristics and performance are discussed below.

14.1 Size and Weight Comparison. Of the four separators tested, only the surge tank and the Intr-Septor meet the 4000-6000 pound weight criteria for a separator system to be used on vessels of opportunity. Both the Alfa-Laval and Vortoil systems tested were considerably heavier, although both companies proposed modifications to bring the weight more in line with logistics requirements. None of the separators included in the program met the 125 cubic foot volume logistics requirements. The Intr-Septor came closest at 195 cubic feet. The Vortoil and Alfa-Laval systems exceeded the target logistics volume by factors of 6.2 and 8.6, respectively.

14.2 Weight to Capacity Ratio Comparison. Figure 146 illustrates the different weight to capacity ratios for the four separators tested. Clearly, the surge tank has the lightest weight per gpm of capacity. Of the three mechanical separators tested, the Intr-Septor had the lowest ratio, at 35 lbs/gpm. The Vortoil system had a weight to capacity of 52, while the Alfa-Laval system ratio was nearly five times greater at 258. It must be noted, however, that the Alfa-Laval system tested in this program was not designed for the specific application of low weight and logistics volume. The Vortoil system was the only separator tested that met the 250 gpm flow capacity requirement.

14.3 Test Result Comparisons. In comparisons of separator performance, it must be kept in mind that the Alfa-Laval system is a proven production model system, whereas both the Vortoil and Intr-Septor systems are prototype models subjected to oil/water mixtures for the first time in this test program. The results from each test series are compared in the following paragraphs.

14.3.1 Crude Oil Test Series. Figures 147, 148, 149 and 150 show the oil content of the water effluent stream, hydrocarbon removal efficiency, free water content of the oil effluent stream and water removal efficiency plotted against influent oil ratio for all separators using the results of the Crude Oil Test Series full capacity test data. These figures show that the Alfa-Laval and Vortoil systems had the best hydrocarbon removal results, but were negatively impacted at high influent oil ratios. Although hydrocarbon removal was comparatively poorer for the Intr-Septor system, it was not negatively affected by influent oil contents as great as 65%.

Figures 149 and 150 show the free water content of the oil effluent stream and water removal efficiency plotted against influent oil ratio for all separators. The Vortoil system showed the best water removal performance at influent oil ratios below 30%, but showed decreasing performance against influent oil ratio. The other mechanical separators had much poorer performance at low influent oil ratios, but showed improved performance with increased influent oil content.

Figure 151 shows a comparison of average mean oil droplet sizes in the free water portions of the influent mixture and the water effluent stream for the Crude Oil Test Series for each separator. Data is included only for those tests where the oil content of the water effluent stream was low and completely dispersed in the free water, so only data for the Alfa-Laval and Vortoil is presented. The figure shows comparable results for these two systems, with remaining mean oil droplet size at 2.9 and 2.5 microns, respectively.

In comparing the results from the Crude Oil Test Series for the separators, the differences in influent oil characteristics must be taken into consideration. Viscosity and density of the influent matched well between the Vortoil and Intr-Septor tests, but the Alfa-Laval system was tested under more favorable conditions, with a lower viscosity fluid and a greater difference in specific gravity between the oil and water in the influent. The interfacial tension test results for samples on the oil used in these tests was comparable between the Alfa-Laval, Vortoil, and Intr-Septor, with a lower value for the oil used in the surge tank tests.

14.3.2 Mousse Test Series. Figures 152, 153, 154 and 155 show the mousse/oil content of the water effluent, hydrocarbon removal efficiency, free water content of the mousse/oil effluent stream and water removal efficiency plotted against influent mousse ratio for the three mechanical separators for the Mousse Test Series. The surge tank was not tested with mousse due to time limitations. These figures show that the Vortoil system performed exceptionally well under these conditions, with the best overall hydrocarbon removal and removal efficiency over all influent mousse to free water ratios. Alfa-Laval performance started out equal to that of the Vortoil system but dropped off with increased mousse content in the influent. The Intr-Septor system had relatively poor hydrocarbon removal performance under these conditions.

Figures 154 and 155 show the free water content of the mousse/oil effluent stream and water removal efficiencies plotted against influent mousse content for the three mechanical separators. Again for this test series, the Vortoil performed considerably better than the other systems, with water removal efficiency consistently greater than 95%. Both the Alfa-Laval and Intr-Septor systems had relatively poor water removal performance, with the Intr-Septor showing improved performance with increasing influent mousse content.

Figure 156 illustrates that none of the separators subjected to the Mousse Test Series had any significant impact on the emulsified water content of the mousse remaining after separation.

Figure 157 shows the change in mean oil droplet size for the Alfa-Laval and Vortoil Mousse Test Series. The Intr-Septor did not produce a clean enough water effluent stream for the droplet size data to be meaningful. The figure shows that the Vortoil was able to remove smaller droplets than the Alfa-Laval during this test series, with remaining mean oil droplet size averaging 21.8 microns for the Alfa-Laval and 5.7 microns for the Vortoil.

In a comparison of test results between the Crude Oil and the Mousse Test Series for these three separators, to determine the impact that influents containing emulsions have on separator performance, the Vortoil system actually showed better performance with the mousse than with a crude oil. The Alfa-Laval system showed a moderate decrease in water removal performance, but only a slight negative impact to hydrocarbon removal. The Intr-Septor showed improved water removal performance with the mousse influent, but a significant drop in hydrocarbon removal performance.

The information at the bottom of Figures 152, 153, 154 and 155 shows the different influent conditions for the Mousse Test Series on the three separators. The mousse produced for the Alfa-Laval tests had a much lower viscosity than either of the other tests, but also a much smaller difference in specific gravity between the emulsion and free water in the influent. Mousse viscosity and the density difference between mousse and free water was comparable between the Vortoil and Intr-Septor tests. The interfacial tension test results for the mousse were comparable between the Alfa-Laval and Vortoil, but both were about 25% lower than that for the Intr-Septor samples. In addition, the average ambient temperature at the test site dropped approximately 11 ° C between the time of the Alfa-Laval and Intr-Septor tests, which could contribute significantly to the stability of the mousse.

Despite the generally less severe influent conditions, the Alfa-Laval system showed a definite impact to operational capability resulting from emulsion in the influent, although this appears to be a problem with the system feed pump and not the centrifuge unit itself. During the 100% mousse influent test on the Alfa-Laval, the influent flow rate had to be reduced because the influent feed pump was unable to keep up with the full capacity target flow rate. The Vortoil system showed no operational impact from mousse at any influent ratio. The Intr-Septor was not tested at 100% mousse due to problems with the test facility equipment, but did show operational limitations with 100% mousse during the Mousse With Emulsion Breaker Test Series after about nine minutes.

14.3.3 Mousse With Emulsion Breaker Test Series. Figures 158, 159, 160, and 161 show the mousse/oil content of the water effluent, hydrocarbon removal efficiency, free water content of the mousse/oil effluent and water removal efficiency plotted against influent mousse content for the three mechanical separators for the Mousse with Emulsion Breaker Test Series. The surge tank was not included in this test due to time limitations. These figures show superior performance for the Intr-Septor system under the higher influent mousse ratio test conditions. The Alfa-Laval system produced better water quality at lower influent mousse content fractions, but performed significantly worse at 100% mousse with emulsion breaker than the Intr-Septor. The Vortoil system produced effluent water with two to three percent mousse/oil content independent of influent mousse content, ranging from 3 to 23 percent. Unfortunately, the Vortoil system was not tested with a 100% mousse influent in this series, so no comparison is possible for this condition.

Figures 160 and 161 show the free water content of the mousse/oil effluent and water removal efficiency plotted against influent mousse content for this test series. Figure 160 shows comparable amounts of water in the mousse/oil effluent stream between the Alfa-Laval and Intr-Septor systems across the entire range of influent conditions, with slightly better water removal efficiency indicated for the Alfa-Laval. However, both figures show the markedly superior performance of the Vortoil system in water removal under these test conditions, with only one to five percent water contained in the mousse/oil effluent stream.

Comparing the results to those from the Mousse Test Series for each of these separators, the Alfa-Laval showed no consistent change in performance, although water effluent quality was slightly degraded over that recorded during the Mousse Test Series. Overall performance of the Vortoil system was degraded with the addition of emulsion breaker. The performance of the Intr-Septor system showed marked improvement with the addition of the emulsion breaker, with mousse/oil content in the water effluent dropping from 27% to 1% for the 50% target mousse influent ratio tests. Water removal performance dropped off moderately with the addition of the emulsion breaker, taking into consideration the added water released from the emulsion.

The information at the bottom of Figures 158, 159, 160, 161 show the differences in influent conditions for the three separators. Again, the influent conditions for the Alfa-Laval test were much milder than those for either the Vortoil or Intr-Septor, with viscosity six to seven times lower than for the other tests, and with a greater difference in specific gravity between the mousse and free water of the influent. The actual dosage rates for the emulsion breaker also varied between the separators. The average rate for both the Alfa-Laval and Intr-Septor was 540 ppm, with 660 ppm for the Vortoil. The interfacial tension test results were comparable between the Alfa-Laval and Vortoil tests, but were significantly higher than those from the Intr-Septor test. As mentioned previously, ambient temperature dropped approximately 11 ° C from the beginning of the tests on the Alfa-Laval through the end of the tests on the Intr-Septor.

14.3.3.1 Impact on Emulsified Water Content. Figure 162 shows the average reduction in emulsified water content after separation for the three separators subjected to the Mousse With Emulsion breakers Test Series. The data show moderate and small decreases for the Vortoil and Intr-Septor, respectively, and a substantial reduction for the Alfa-Laval tests. The demulsification shown for the Alfa-Laval is primarily due to the large reduction in emulsified water content noted during the 100% mousse influent test. This was the only test in this series with the Alfa-Laval where emulsified water content was observed to drop substantially due to the addition of the emulsion breaker.

14.3.3.2 Impact of Emulsion Breaker on Viscosity. Figure 163 shows consistent and substantial decreases in viscosity due to the addition of Breaxit 7877 to the influent stream. The average net drop in viscosity after separation using the

emulsion breaker was roughly 3600 cP (shear rate = 10 sec^{-1}, 19° C average), 19,000 cP (shear rate = 10 sec^{-1}, 14° C average), and 30,000 cP (shear rate = 10 sec^{-1}, 16° C average), for the Alfa-Laval, Vortoil and Intr-Septor, respectively. These represent decreases of 81%, 85% and 94%, respectively, in the original viscosity of the influent mousse prior to the addition of Breaxit 7877.

14.3.3.3 Change in Droplet Size After Separation. Figure 164 shows the average change in mean oil droplet size after separation for the Alfa-Laval. Because neither the Vortoil nor Intr-Septor produced a clean enough water effluent stream contained only dispersed oil, the droplet size data from the Mousse With Emulsion Breaker Test Series on these two systems is not meaningful. Figure 164 shows that the average mean oil droplet size in the free water portion of the influent stream was very small. This was observed in the Mousse With Emulsion Breaker Test Series on all separators. For the Alfa-Laval, the oil droplet size in the water effluent stream is slightly larger than in the influent, on average. The size of the oil droplets is extremely small, however, and the change is not significant.

14.3.4 Debris Test Series. Figures 165, 166, 167, and 168 show the oil content of the water effluent, hydrocarbon removal efficiency, free water content of the oil effluent stream and water removal efficiency plotted against time for the three mechanical separators for the Debris Test Series. The surge tank was not included in this test series due to time limitations. These figures show that the separation performance of neither the Vortoil nor the Intr-Septor was severely impacted by debris. The degradation in performance of the Alfa-Laval with increasing minutes of debris addition can be seen in each figure.

The Intr-Septor was the only separator that demonstrated the capability of withstanding the full 45 minute debris addition test of this series. The Vortoil Debris Test Series was aborted after 43 minutes of debris addition, and the Alfa-Laval test after 32 minutes. Both Alfa-Laval and Conoco have proposed modifications to their system that should eliminate the limitations, however.

The information at the bottom of Figures 165, 166, 167 and 168 shows the differences in influent conditions for the three separators. For this test series, oil viscosity was comparable between the Alfa-laval and Intr-Septor tests, but the Vortoil was subjected to an oil with roughly double that viscosity for the Debris Test Series. The differential specific gravity for the Alfa-Laval tests was nearly 50% greater than those in the Vortoil and Intr-Septor tests. The interfacial tension test results were comparable between the Vortoil and Intr-Septor tests, but the data from the Alfa-Laval test on interfacial tension is not considered valid.

14.3.5 Other Performance Related Observations

14.3.5.1 Ability to Handle 100% Water, 100% Oil or Mousse Influents. The Vortoil system was the only separator tested that demonstrated the capability to effectively handle influents of 100% water, oil or mousse.

14.3.5.2 Impact of Sea Motion. None of the mechanical separators were significantly impacted by simulated sea motion.

14.3.5.3 Impact of Reduced Capacity. Only the Vortoil system and surge tank were tested at reduced capacity. Because the results from the surge tank were inconclusive, there is no viable comparison between separators. The impact of reduced capacity to the Vortoil system is discussed in more detail in section 12.3.3.3 of this report.

14.3.5.4 Impact on Emulsified Water Content During Separation. Neither the Alfa-Laval nor the surge tank produce any noteworthy increase in emulsified water content as a result of separation. Emulsified water content increased significantly for some tests on the Vortoil using crude oil, and some small to moderate increases were observe during the Intr-Septor tests that used crude oil (Crude Oil and Debris Test Series).

14.3.5.5 Oil Droplet Size Remaining in Water Effluent Stream. Figure 169 show the average of the mean oil droplet size data for each separator and test series. The data shown represents only those tests where the water effluent stream contained only dispersed oil in free water, since the data from tests where there were large quantities of non-dispersed oil in the water effluent stream is not meaningful. For each separator, there were one or more tests where the water effluent stream contained significant amounts of non-dispersed oil. For those tests where the separators did perform well in removing oil and mousse, Figure 169 does illustrate that the remaining droplet sizes are very small, with the mean below 25 microns.

15.0 COMPARISON OF SYSTEM CHARACTERISTICS

15.1 Special Operating Characteristics. Only the Alfa-Laval system was capable of producing enough pressure in the effluent lines so that secondary pumps were not required to move the effluents to the reclaimed oil and water effluent tanks at the test facility. This would be a benefit for an operational system, in that secondary pumps may not be required to move the effluents to storage or over-boarding.

15.2 Transportability. All systems except for the Alfa-Laval were easily transported using a standard forklift. Due to the weight of the Alfa-Laval, a heavy duty forklift required to position it at the test site.

15.3 Reliability. Both the Alfa-Laval and the surge tank showed excellent reliability. Both the Vortoil and Intr-Septor system exhibited some operational problems during the tests, but proposed design modifications have been made by both manufacturers to eliminate the problems. Both of these systems were prototype units, never before tested under realistic operating conditions.

15.4 Maintenance. Maintenance requirements were negligible for all separators. The Intr-Septor required relatively frequent greasing of bearings, but this requirement has been significantly reduced in the improved design proposed by the manufacturer.

15.5 Operability. The surge tank and Intr-Septor both were extremely easy to set up and operate. Set up and operation of the Vortoil would require some training, but a dedicated operator is not required for operation. The Alfa-Laval system had the highest operations requirement, with a trained operator needed to set-up and monitor the system.

15.6 Safety. No unusual safety hazards were identified for any of the separators tested over the course of the test program.

16.0 RECOMMENDATIONS FOR FURTHER SYSTEM IMPROVEMENT

In addition to the system improvements recommended by the manufacturers of the three mechanical separators, the following additional improvements are recommended.

16.1 Alfa-Laval OFPX 413. A larger capacity feed pump is needed for the system. The feed pump supplied with the unit often limited the capacity of the system. This was observed particularly during the tests that used mousse in the influent. In addition, mechanical connections between the centrifuge containerized unit and the base would provide more stability. The lowered center of gravity achieved by reducing the volume of the solids discharge holding tank in the base also is recommended for a more portable system.

16.2 Vortoil Oilspill Separation System. No other recommended modifications were identified.

16.3 Intr-Septor 250. To improve reliability under realistic operating conditions, all exposed components should be weatherproof and built for marine applications.

17.0 RECOMMENDATIONS FOR ADDITIONAL TESTING

The following recommendations for additional testing of each separator are based on each separator's overall performance during the test program, as well as modifications proposed by the manufacturers to improve performance.

17.1 Alfa-Laval OFPX 413. If Alfa-Laval develops a system that incorporates the modifications proposed by the manufacture, including reduced system weight, increased capacity and improved water removal efficiency resulting from design

changes in the effluent pumping systems, inclusion of a first stage surge tank to prevent 100% oil or mousse influents, and installation of a self-cleaning debris screen, and the new system weight and capacity are appropriate for USCG and MSRC operational scenarios, the following performance tests are recommended:

1. The Crude Oil and Mousse Test Series documented in this report should be repeated, to determine the extent of improvement in overall capacity and water removal, and any resulting effect on hydrocarbon removal performance. In particular, the Mousse Test Series should be conducted with an emulsion more in line with the target properties identified for this test program. Because of uncontrollable irregularities in the characteristics of the crude oil available at the test site, the Alfa-Laval was tested under much less severe conditions than the other separators.

2. A heavier oil test, using a Bunker-C type oil, should be included in any additional tests on the Alfa-Laval system to determine the impact that high viscosity, high density oil has on separator performance.

3. The system should be re-tested under the Debris Test Series conditions from this program to determine the effectiveness of the strainer system, and any limits of its operation. If the system performs well, the amount of debris should be increased to test the system under harsher, more realistic operational conditions.

4. If any additional tests are conducted on the Alfa-Laval separator, the limiting oil/water ratio for the system should be determined. During the tests documented in this report, the Alfa-Laval system produced extremely clean water for influent oil ratios up to 61%, but was incapable of handling 100% oil. It would be of interest to determine at what influent oil content water effluent quality begins to drop off.

17.2 Surge Tank. The poor results from tests on the surge tank included in this test series are primarily believed to be due to restrictions in the oil effluent line, and perhaps other design considerations that were overlooked when modifying a 100 gpm separator to function as a 250 gpm unit. It is recommended that the surge tank design be revisited and modified to ensure, at a minimum, that a 250 gpm capacity can be achieved. This may require additional modifications to the interior of the system, as well as providing appropriate discharge line characteristics. While a test program dedicated to obtaining performance results on a surge tank alone is not warranted, including a redesigned surge tank in future test programs is recommended, especially if information regarding the benefit of including such a tank as a first stage to another system is still under consideration. The data also would provide a good baseline of performance results against which to compare more sophisticated systems.

If additional testing is undertaken on the surge tank, it is recommended that the tests include the parameters and variables of the Crude Oil, Sea Motion, Mousse, Mousse with Emulsion Breaker, and Debris Test Series. A heavy oil test, using a

Bunker C type oil also should be included to determine the impact that a heavy high viscosity oil has on separator performance.

17.3 Vortoil Oilspill Separation System. After modification of the Vortoil system, as proposed by Conoco, if the new weight and footprint of the Vortoil system meets USCG and MSRC logistics requirements, the following additional performance tests are recommended:

1. With larger oil effluent return lines from the hydrocyclones, as proposed by Conoco, the Vortoil system should perform better at higher influent oil ratios. In addition, adjusting the system controls to provide for better hydrocarbon removal, as recommended by Conoco following the test program, should provide for better hydrocarbon removal at high influent ratio, but at some expense to water removal. It is recommended that the system be tested twice under the conditions of the Crude Oil Test Series described in this report, to determine first the improvements made by substituting the larger oil effluent piping, and then tested again with the control setting adjusted for highest hydrocarbon removal performance if warranted from the results of the first test series. If re-adjustment of the controls is necessary to provide good water quality, any resulting negative impact to water removal should be documented.

2. Depending on the results of the tests above, the limiting oil/water ratio for the Vortoil system under crude oil conditions should be determined, to identify at what influent oil ratio, if any, water effluent hydrocarbon removal performance begins to drop off.

3. The modified Vortoil system also should be re-tested under debris conditions to determine if there is any impact from the removal of the first stage duplex strainer, and to determine the effectiveness and operability of the duplex strainer system placed before the hydrocyclone stages. If the system performs well, the Increased Debris Test Series also is recommended to evaluate performance under harsher but more realistic operating conditions.

4. A heavy oil test, using a Bunker C type oil, should be conducted on the modified system to quantify any impacts to performance resulting from increased viscosity and density.

5. If there is interest in determining the effectiveness of the chemical injection system available with the system, the Mousse With Emulsion Breaker Test Series should be repeated. The results should then be compared to those for the re-test of the Mousse Test Series. If the chemical injection does not make a significant improvement in demulsification, repeating portions of the test series with the same chemical injected upstream of the separator should be considered to determine the impact of reaction time and mixing on emulsion breaker performance with the Vortoil system.

6. All tests should be conducted with an operationally realistic back pressure on the oil effluent line to test the modifications to the oil effluent system.

7. During any tests performed on the Vortoil, it is recommended that samples occasionally be drawn from the oil effluent stream of the hydrocyclones before recycling to the surge tank, if possible, to determine the emulsified water content of this oil stream. Moderate to significant increases in emulsified water content were observed during both the Crude Oil and Debris Test Series, and it would be worthwhile to determine if the emulsification was occurring primarily within the hydrocyclones, or within the surge tank.

17.4 Intr-Septor 250. International Separation Technology proposed significant and substantial modifications to their system to improve performance based on the tests of the their prototype unit during this test program. The sweeping changes should considerably improve performance, and additional testing is recommended to evaluate the new system. The following tests are recommended on the new system:

1. Re-test the system under the conditions of the Crude Oil Test Series documented in this report, including the reduced capacity tests which were not performed in this test program. For at least one test of the series, repeat the test using the compressed air injection mechanism on the new system to quantify the improvement in separation gained by entraining air in the influent stream. If the standard system operating procedure is to use the compressed air mechanism at all times, conduct the entire test series under these conditions, and then repeat at least one test without the use of injected air.

2. Re-test the system under the conditions of the Mousse Test Series, again to document improvements in performance due to system modification. For at least one test in the series, repeat the test using the compressed air injection mechanism on the new system to quantify the improvement in separation gained by entraining air in the influent stream. If the standard system operating procedure is to use the compressed air mechanism at all times, conduct the entire test series under these conditions, and then repeat at least one test without the use of injected air.

3. A heavy oil test, using a Bunker C type oil, should be included to determine the impact that high viscosity, high specific gravity un-emulsified oils have on performance. For at least one test of the series, repeat the test using the compressed air injection mechanism on the new system to quantify the improvement in separation gained by entraining air in the influent stream. If the standard system operating procedure is to use the compressed air mechanism at all times, conduct the entire test series under these conditions, and then repeat at least one test without the use of injected air.

4. Conduct the Debris Test Series under the same or greater debris addition amounts to determine if the gradual increase in pressure is due to debris impacting the system. Inspect the system internally after the conclusion of the test series to document if there is any debris build-up inside the system. If the results from the tests described above that incorporate tests of the compressed air injection system produce favorable results, conduct an abbreviated debris test (after cleaning out the system, if required) with the air injection mechanism, and compare the results with those from the beginning of the Debris Test Series conducted without air injection. As in the previous test recommendations, if the standard system operating procedure is to use the compressed air mechanism at all times, then conduct the entire test series with the use of air, and repeat the abbreviated debris addition test without injected air.

5. If the results of the previous tests indicate a drop in performance with increased oil in the influent, the limiting oil/water ratio should be determined to quantify at what influent oil ratio performance is significantly affected.

6. If there is interest in determining the effectiveness of the chemical injection system included in the new design, the Mousse With Emulsion Breaker Test Series should be repeated. The results should then be compared to those for the re-test of the Mousse Test Series. If the chemical injection does not make a significant improvement in demulsification, repeating portions of the test series with the same chemical injected upstream of the separator should be considered to determine the impact of reaction time and mixing on emulsion breaker performance with the Intr-Septor system.

18.0 REFERENCES

1. MAR, Incorporated, Strike Team Oil Recovery Equipment Upgrade Test and Evaluation, Oil/Water Separator Survey Report, Draft Final Report, Technical Report No. 1027, Rockville, MD, January 1992.

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3. "Standard Guide for Evaluation of Oil Water Separation Systems for Spilled Oil Recovery Applications", Designation: F933-85, 1992 Annual Book of ASTM Standards, Vol. 11.04, pp 1298-1300, Philadelphia, PA, 1992.

4. Lambert, P.G., Bobra, M.A., Fingas, N.F., Tennyson, E.J., Gould, J.R., Development of a Portable Field Kit for Measuring Properties of Spilled Oils, Proceedings of the 14th Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Edmonton, Alberta, Canada, pp 73-86, 1991.

5. Murdoch, M.A., Evaluating Oil/Water Separators, Proceedings of the 16th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Environment Canada,m Edmonton, Alberta, Canada, Vol. 1, pp 435-449, June 1993.

6. Knut Gåseidnes, Miljø & Ånlegg, Trondheim, Norway, Personal communication, March 1993.

7. Geoff Hinshelwood, Environmental Testing Services, Inc., Norfolk, Virginia, Personal communication, April 1993.

8. William Bowers, Conoco Specialty Products, Inc., Houston, Texas, Personal communication, April 1993.

Figure 1: Test Site Schematic

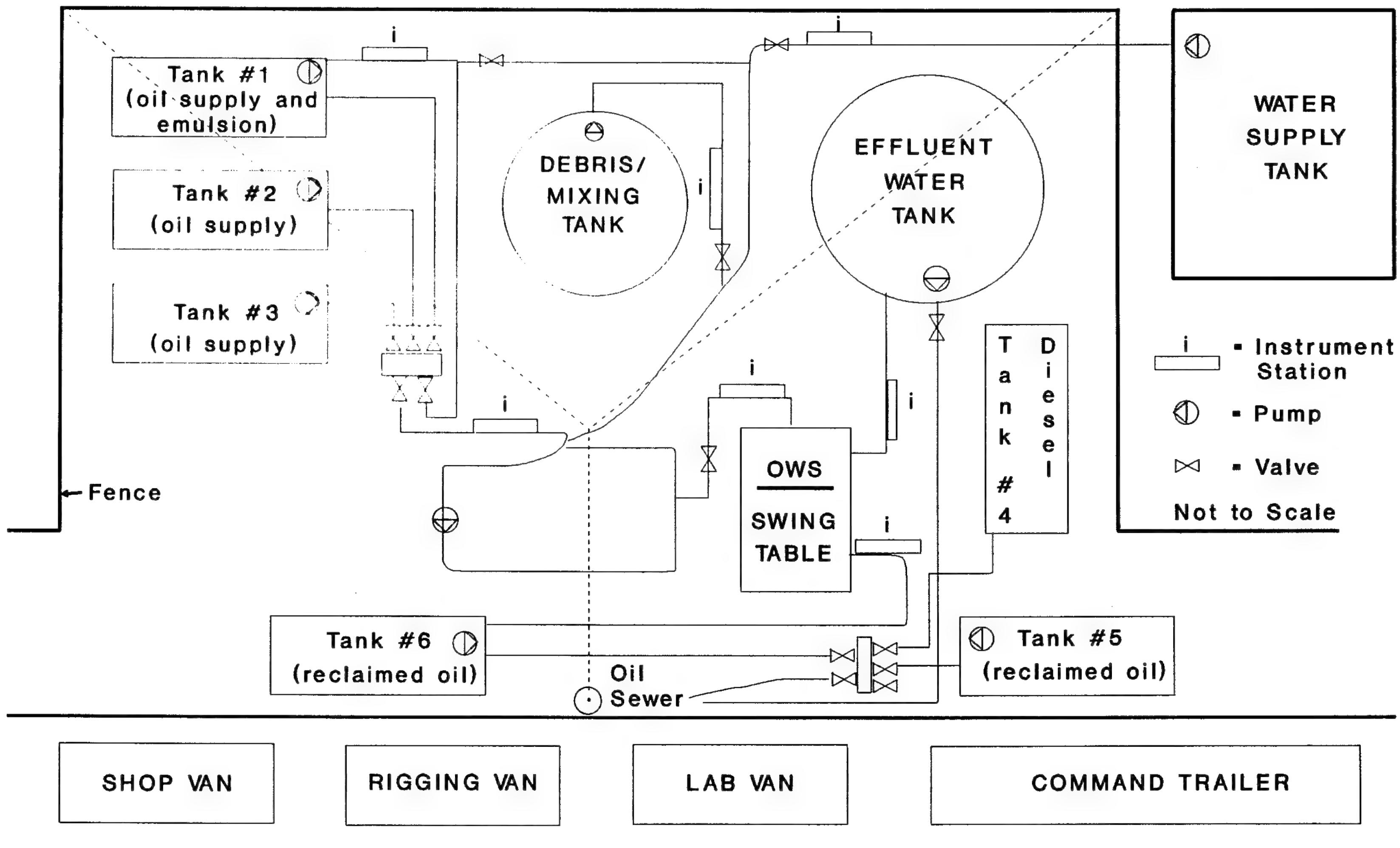
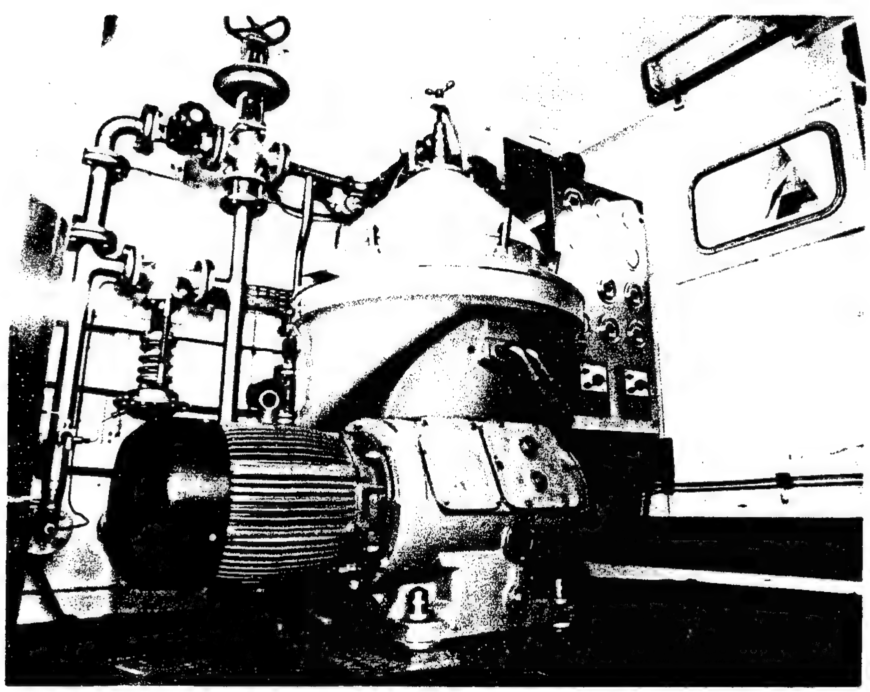


Figure 2: Test Facility

Figure 3: Alfa-Laval Disk-Stack Centrifuge



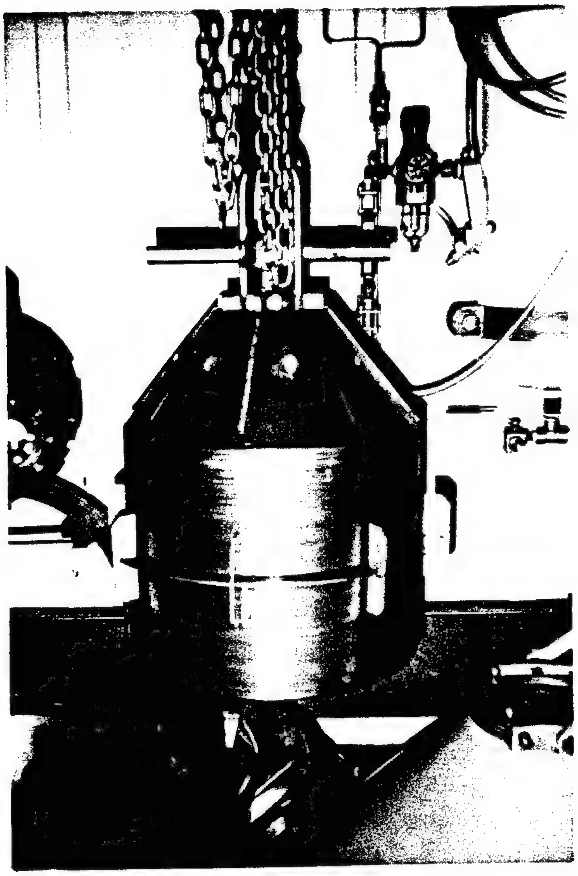


Figure 4:
Alfa-Laval Disk-Stack
Being Placed Into
Centrifuge Bowl

Figure 5: Containerized Alfa-Laval System

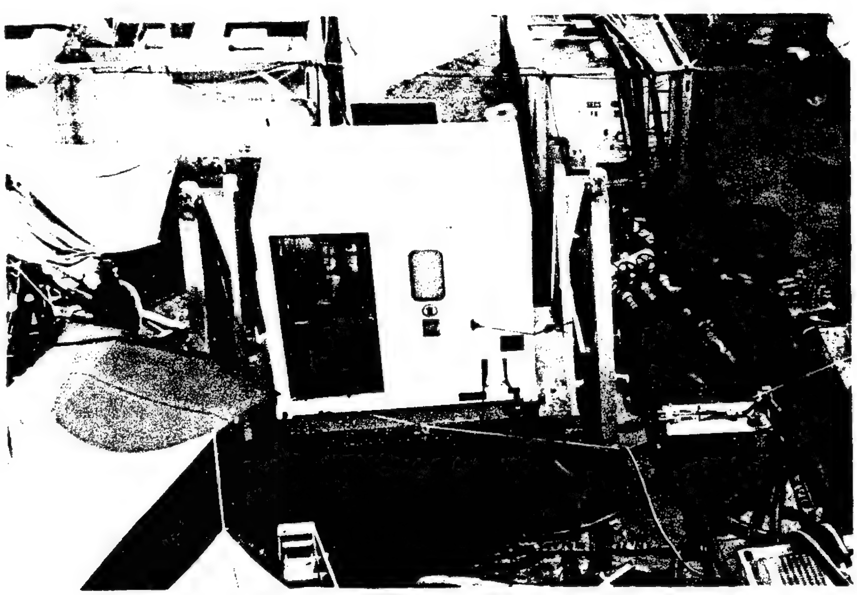


Figure 6: Alfa-Laval Feed Pump

Figure 7: Test Facility Set-Up for Alfa-Laval

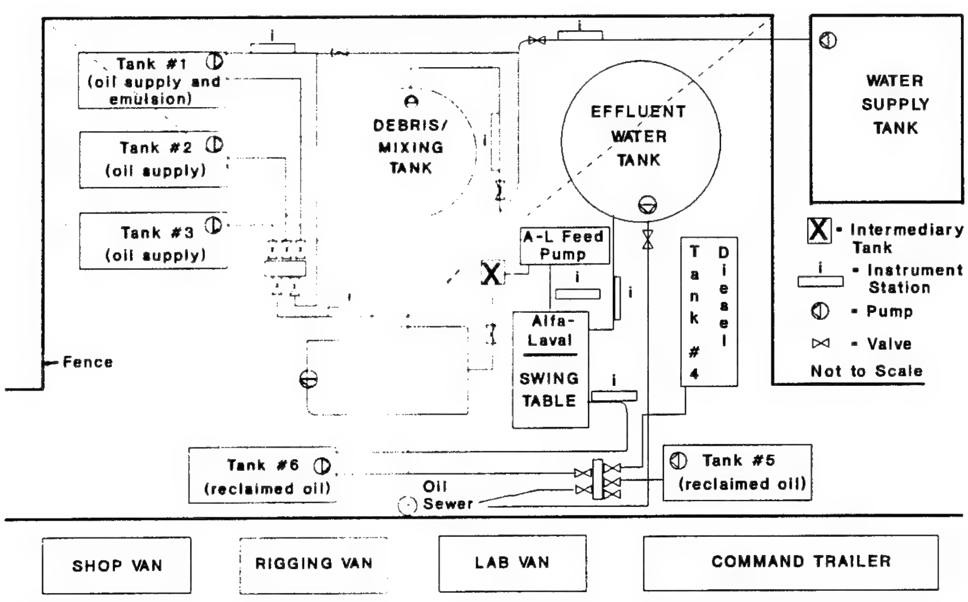


Figure 8a:

Alfa-Laval Crude Oil Test Series
Test #1: 100% Water Influent
67 gpm

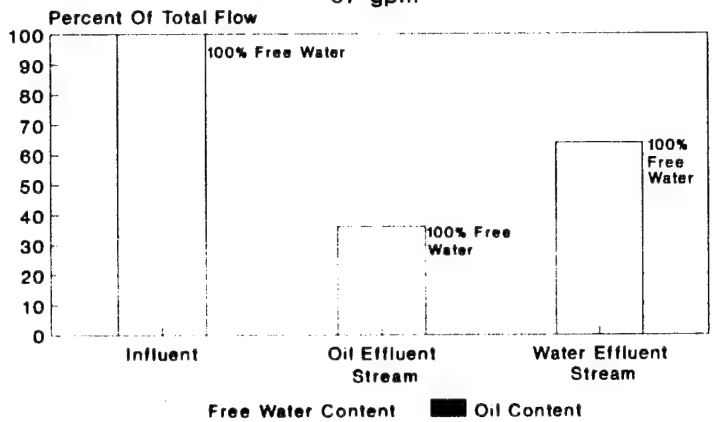


Figure 8b:

Alfa-Laval Crude Oil Test Series
Test #2: 11% Influent Oil Content
67 gpm

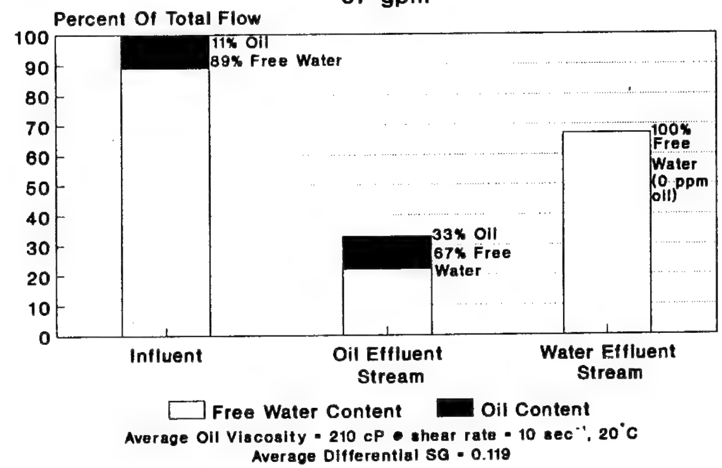


Figure 8c:

Alfa-Laval Crude Oil Test Series
Test #3: 27% Influent Oil Content
63 gpm

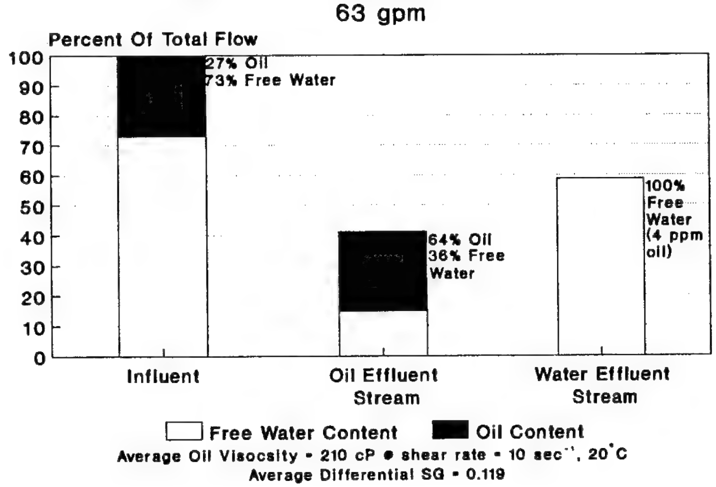


Figure 8d:

Alfa-Laval Crude Oil Test Series
Test #4: 37% Influent Oil Content
56 gpm

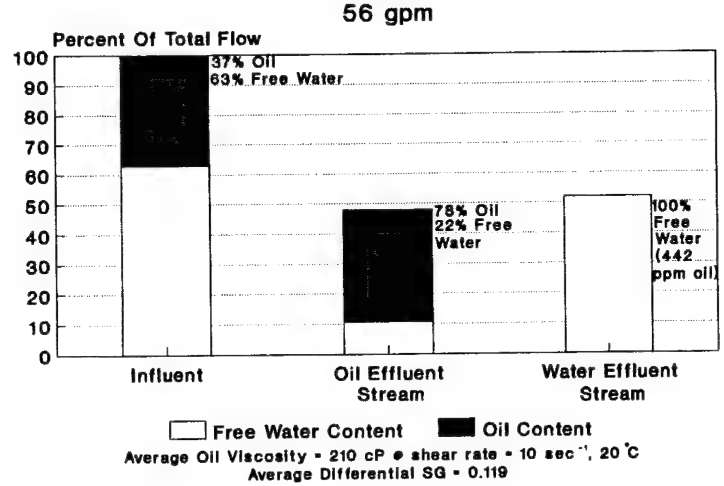
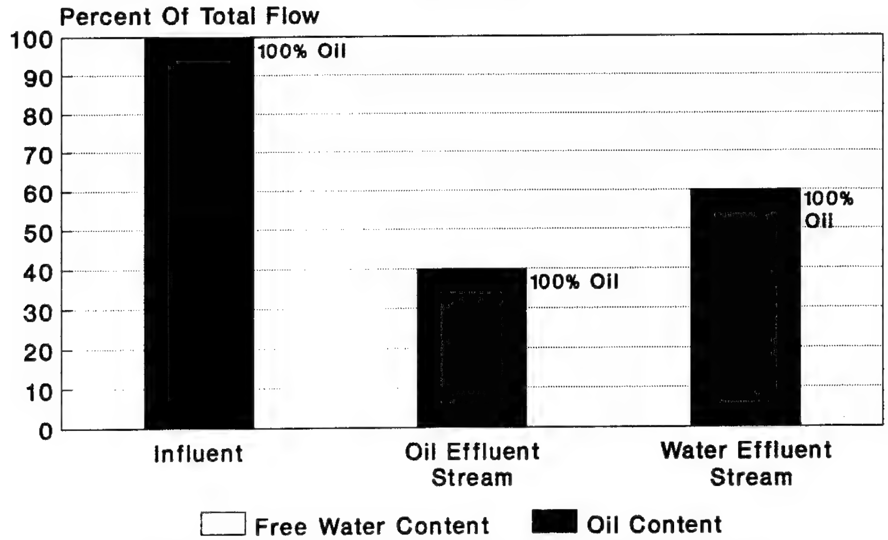


Figure 8e:

Alfa-Laval Crude Oil Test Series
Test #5: 100% Oil Influent
45 gpm



Average Oil Viscosity = 210 cP @ shear rate = 10 sec^{-1}, 20°C

Figure 8f:

Alfa-Laval Crude Oil Test Series
Test #6: 100% Water Influent
54 gpm

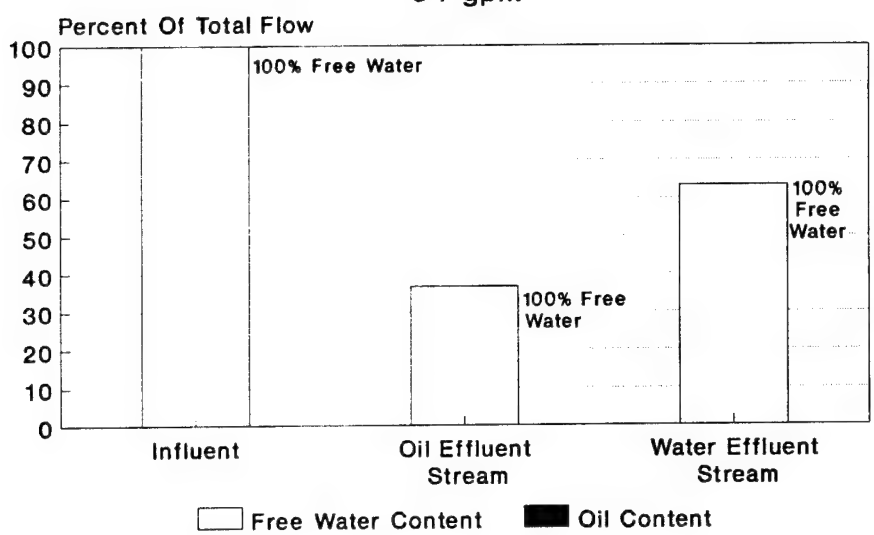
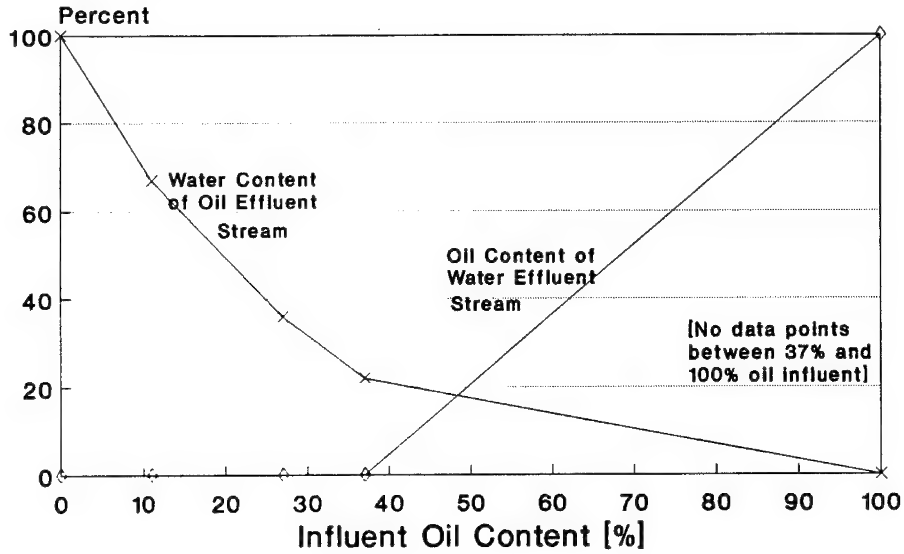
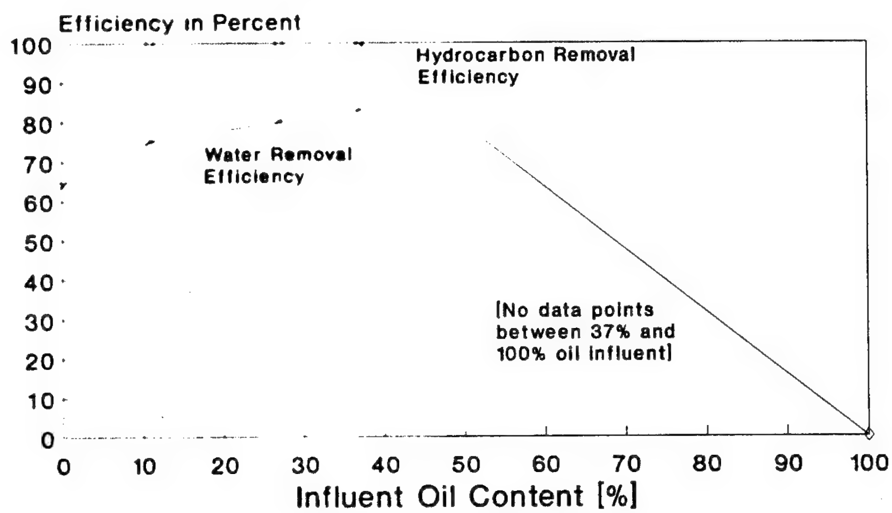


Figure 9:
Alfa-Laval Crude Oil Test Series
Effluent Composition vs. Influent Oil Content



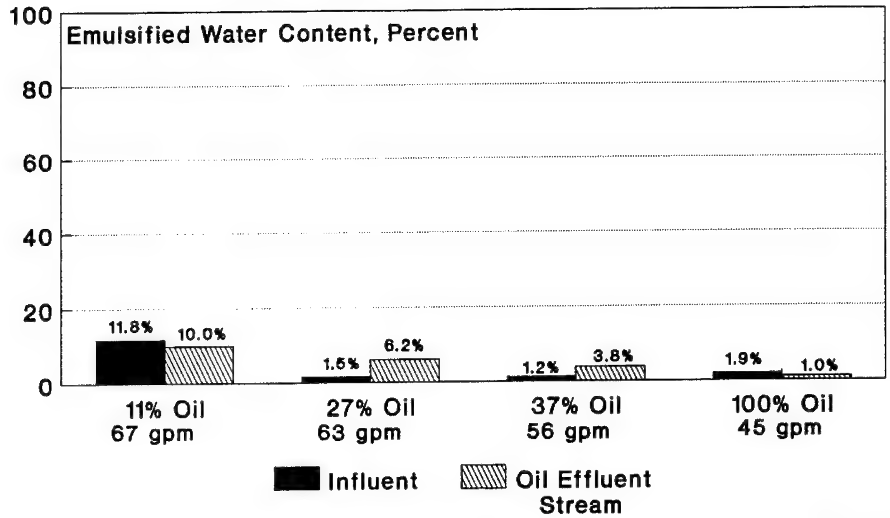
Average Flow Rate = 59 gpm
Average Oil Viscosity = 210 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.119

Figure 10:
Alfa-Laval Crude Oil Test Series
Efficiency vs. Influent Oil Content



Average Flow Rate = 59 gpm
Average Oil Viscosity = 210 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.119

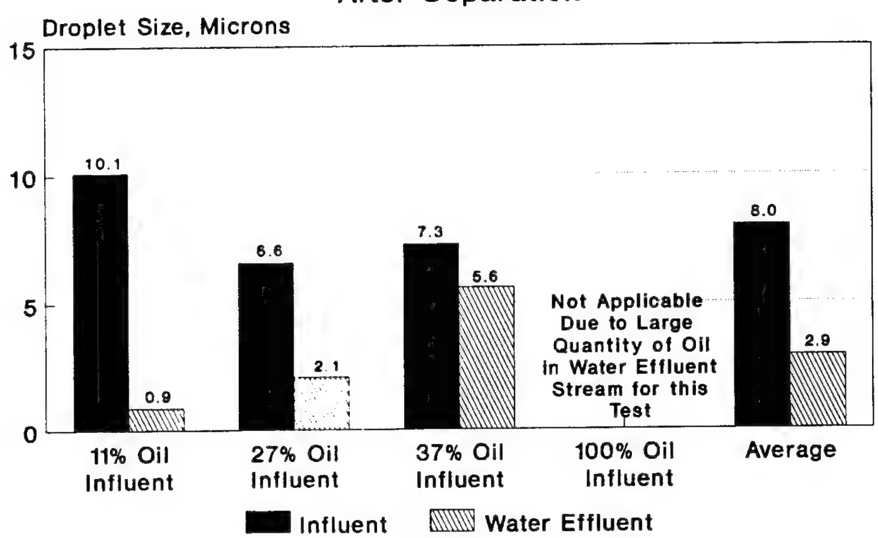
Figure 11:
Alfa-Laval Crude Oil Test Series
Emulsified Water Content
Before and After Separation



Average Flow Rate = 59 gpm
Average Oil Viscosity = 210 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.124*

* Includes impact of emulsion breaker

Figure 12:
Alfa-Laval Crude Oil Test Series
Change in Mean Oil Droplet Size
After Separation



Average Oil Viscosity = 210 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.119

Figure 13:
Alfa-Laval Crude Oil Test Series
Influent and Effluent Line Pressure
vs. Time

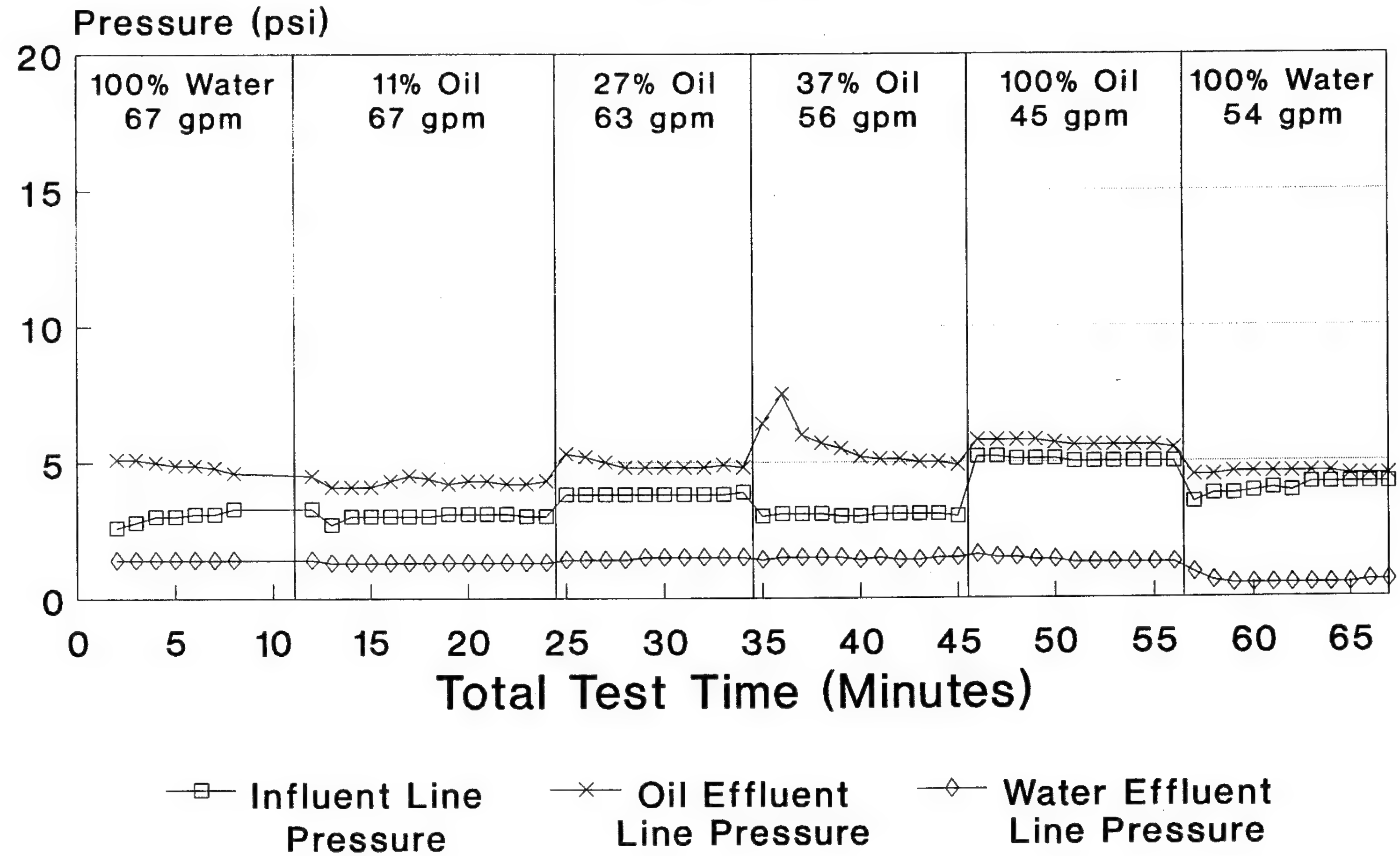


Figure 14a:
Alfa-Laval Sea Motion Test Series
Test #1: 100% Water Influent
73 gpm

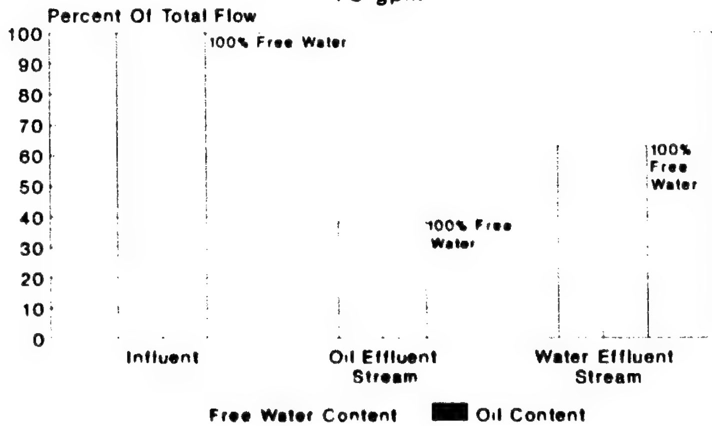


Figure 14b:
Alfa-Laval Sea Motion Test Series
Test #2: 17% Influent Oil Content
73 gpm

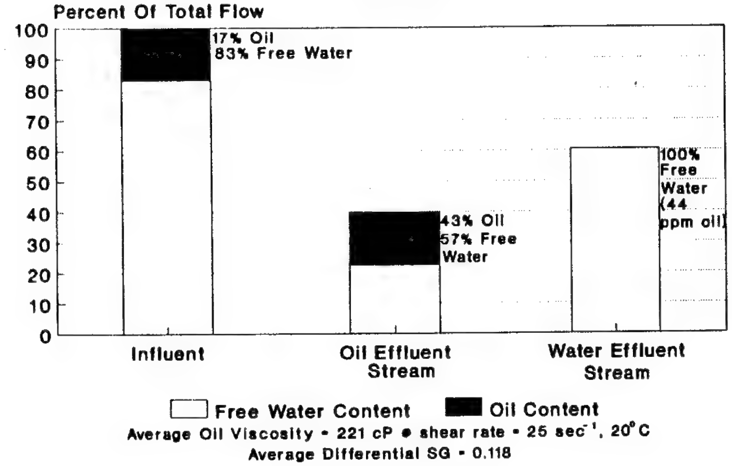


Figure 14c:
Alfa-Laval Sea Motion Test Series
Test #3: 41% Influent Oil Content
43 gpm

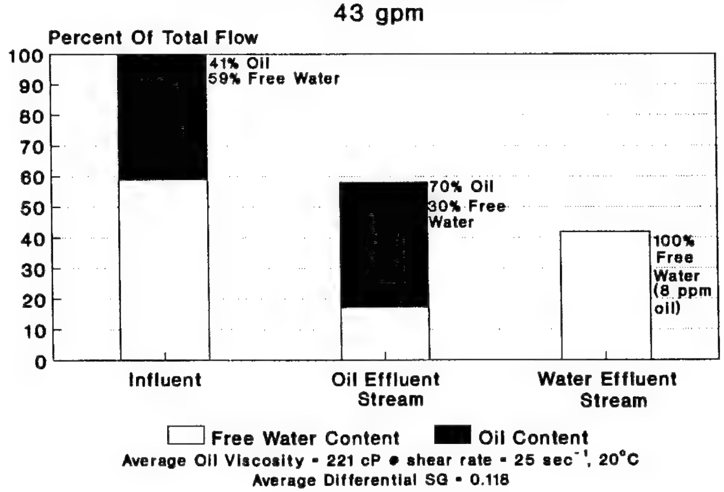


Figure 14d:
Alfa-Laval Sea Motion Test Series
Test #4: 61% Oil Influent Content
45 gpm

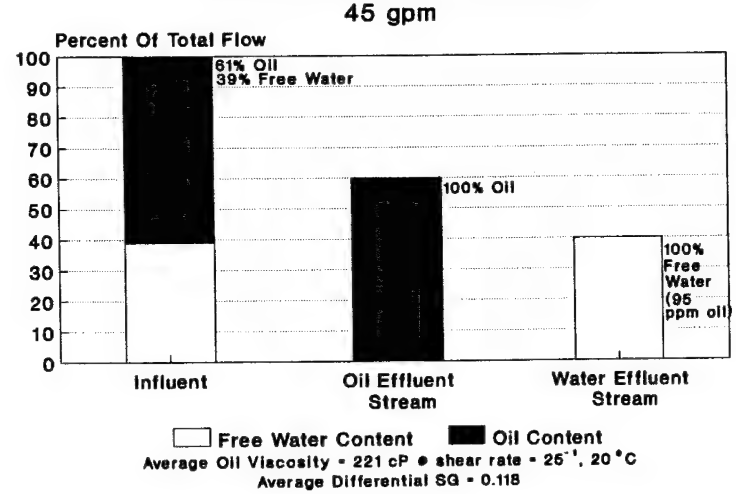


Figure 14e:
Alfa-Laval Sea Motion Test Series
Test #5: 100% Water Influent
52 gpm

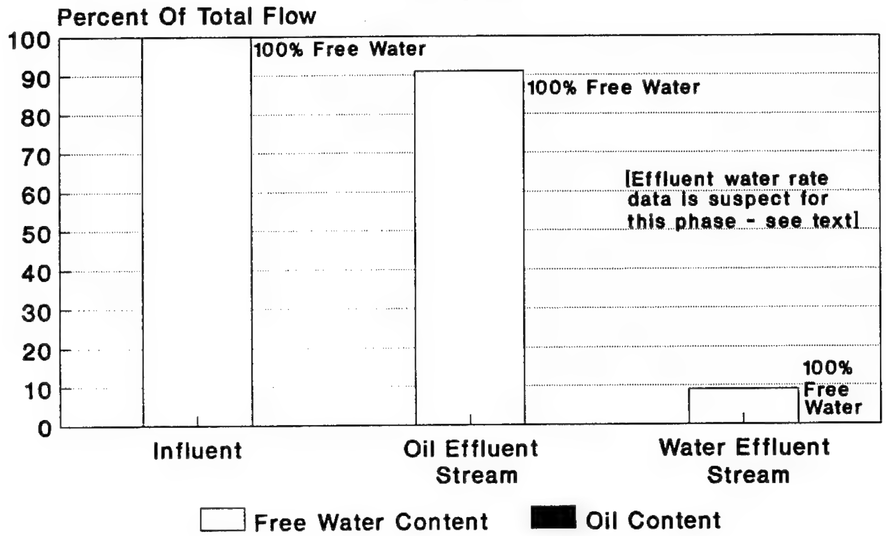
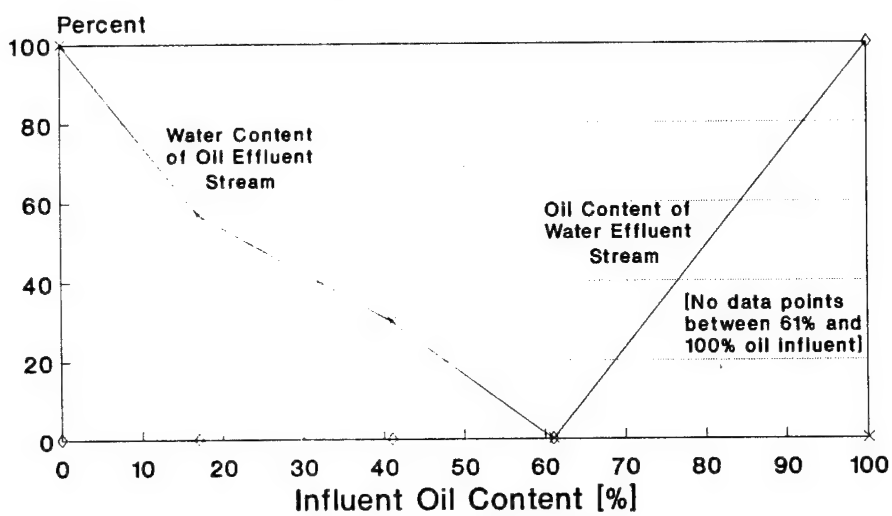


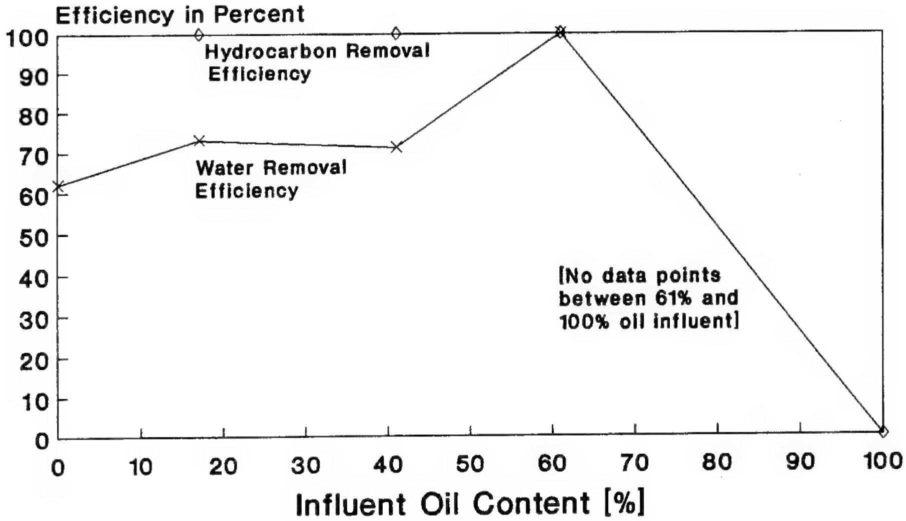
Figure 15:
Alfa-Laval Sea Motion Test Series
Effluent Composition vs. Influent Oil Content



Average Flow Rate = 57 gpm
Average Oil Viscosity = 221 cP @ shear rate = 25 sec^{-1}, 20°C
Average Differential SG = 0.118

Figure 16:

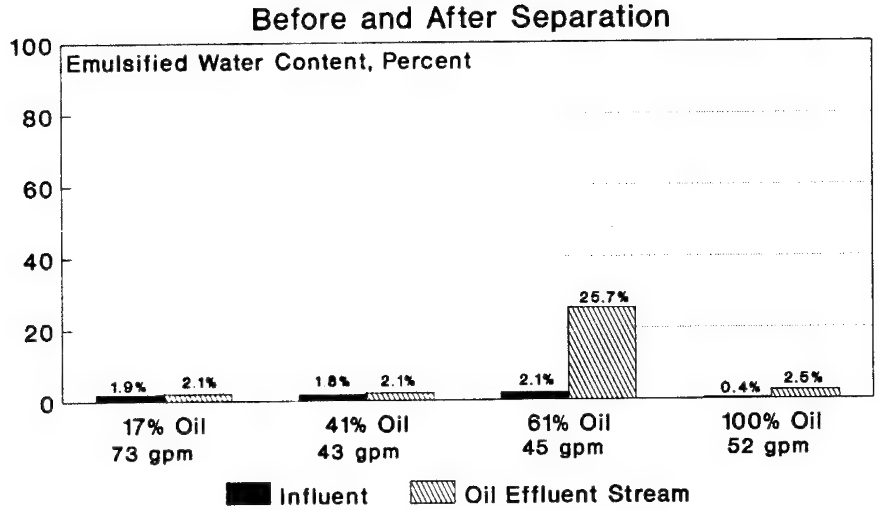
Alfa-Laval Sea Motion Test Series
Efficiency vs. Influent Oil Content



Average Flow Rate = 57 gpm
Average Oil Viscosity = 221 cP @ shear rate = 25 sec^{-1}, 20°C
Average Differential SG = 0.118

Figure 17:

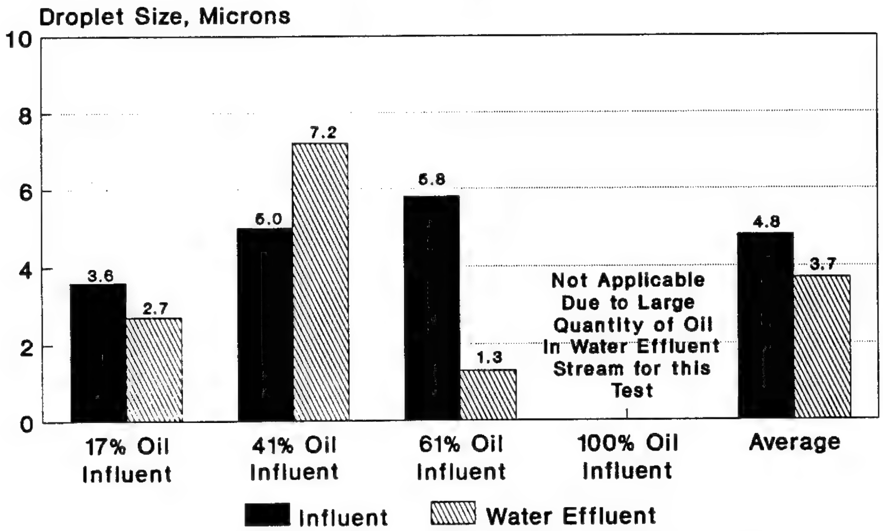
Alfa-Laval Sea Motion Test Series
Emulsified Water Content
Before and After Separation



Average Flow Rate = 57 gpm
Average Oil Viscosity = 221 cP @ shear rate = 25 sec^{-1}, 20°C
Average Differential SG = 0.118

Figure 18:

Alfa-Laval Sea Motion Test Series
Change in Mean Oil Droplet Size
After Separation



Average Oil Viscosity = 221 cP @ shear rate = 25 sec^{-1}, 20°C
Average Differential SG = 0.118

Figure 19:

Alfa-Laval Sea Motion Test Series
Influent and Effluent Line Pressure
vs. Time

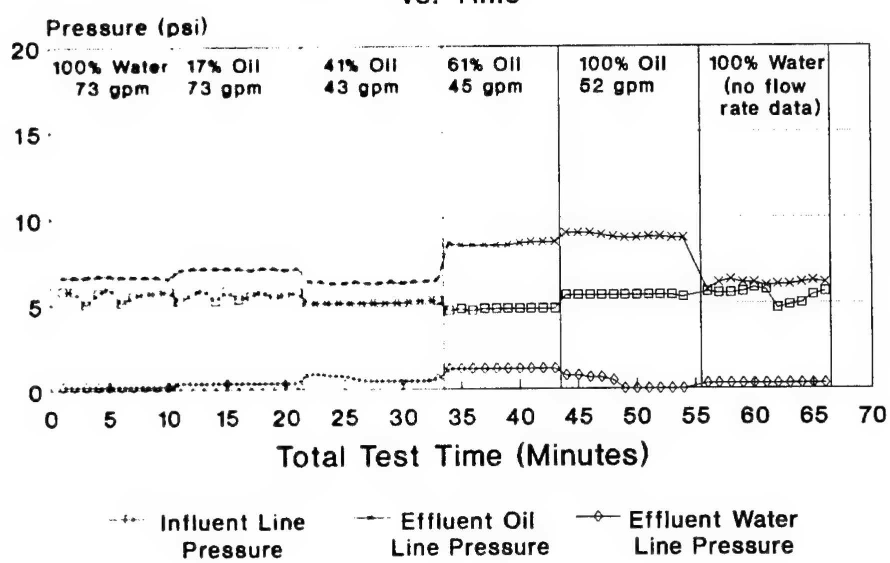


Figure 20:

Impact of Sea Motion on Alfa-Laval:
Oil Content in Water Effluent Stream vs. Influent Oil Content for Crude Oil and Sea Motion Test Series

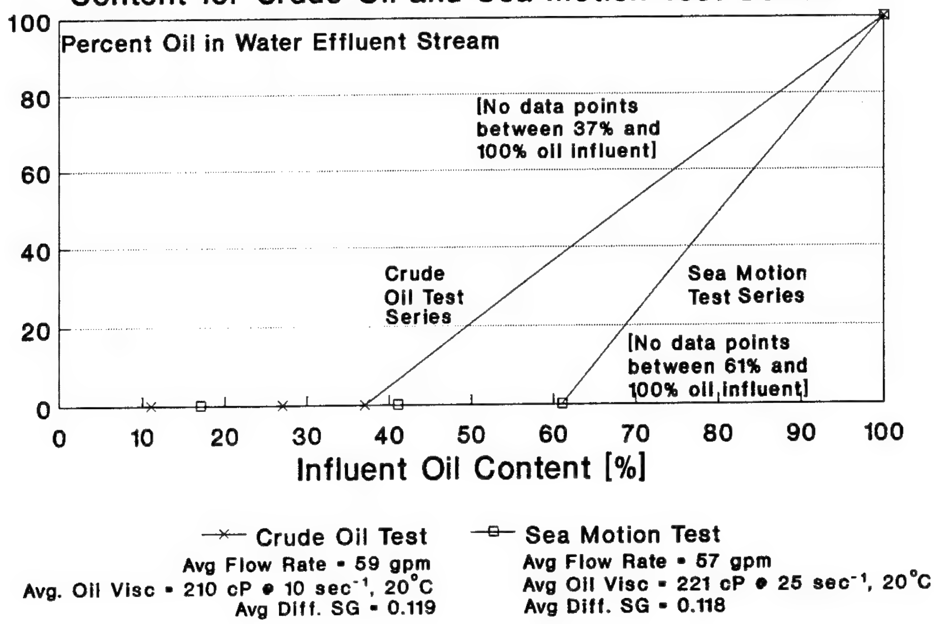


Figure 21:

Impact of Sea Motion on Alfa-Laval:
Oil Effluent Water Content vs. Influent Oil Content for Crude Oil and Sea Motion Test Series

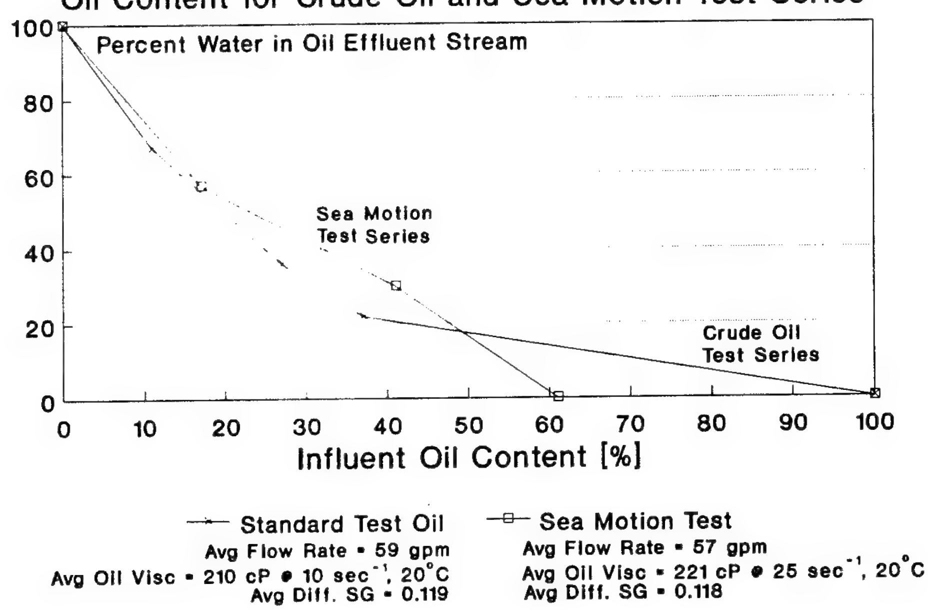


Figure 22:

Impact of Sea Motion on Alfa-Laval:
Water Removal Efficiency vs. Influent
Oil Content for Crude Oil and Sea Motion Test Series

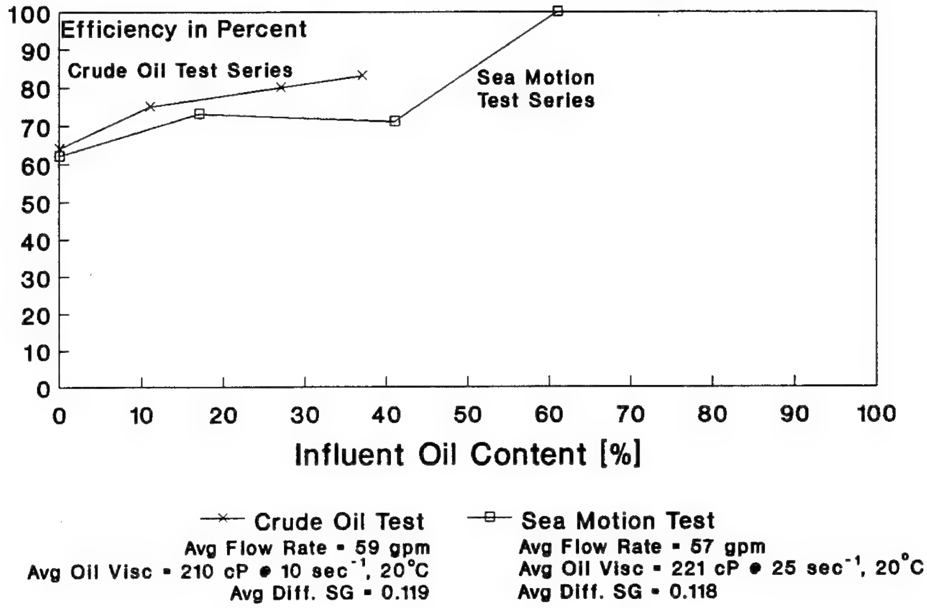


Figure 23:

Impact of Sea Motion on Alfa-Laval:
Hydrocarbon Removal Efficiency vs. Influent Oil
Content for Crude Oil and Sea Motion Test Series

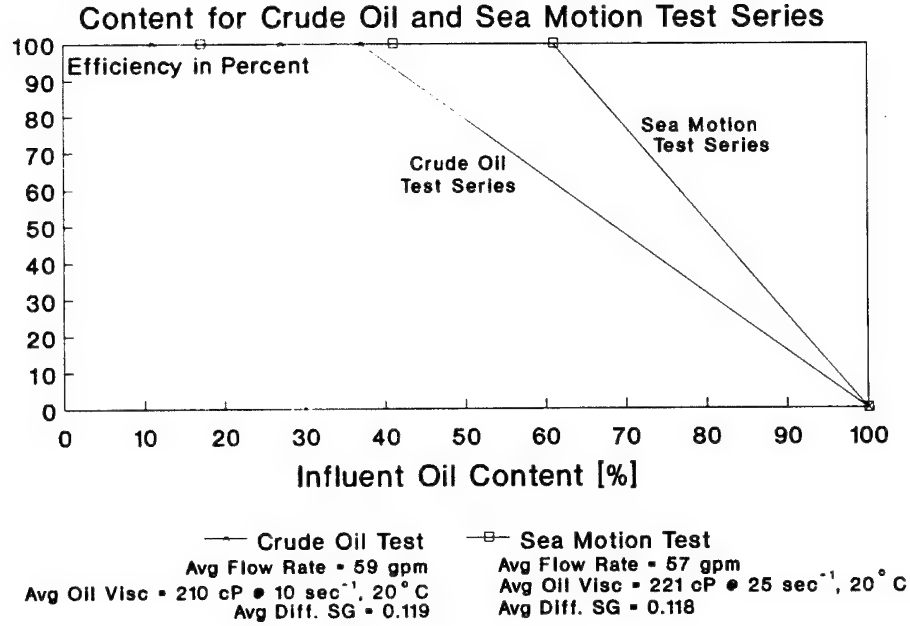


Figure 24a:
Alfa-Laval Mousse Test Series
Test #1: 100% Water Influent
58 gpm

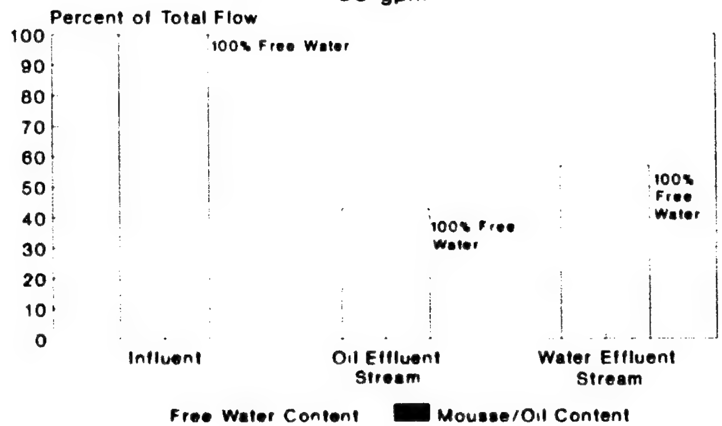


Figure 24b:
Alfa-Laval Mousse Test Series
Test #2: 5% Influent Mousse Content
68 gpm

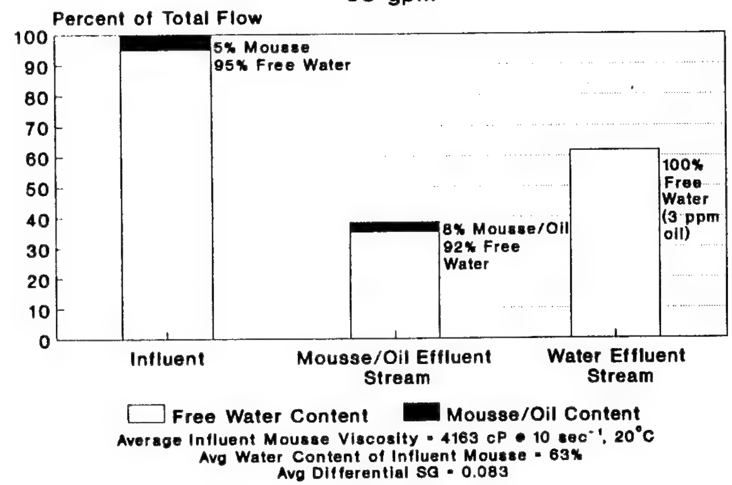


Figure 24c:
Alfa-Laval Mousse Test Series
Test #3: 23% Influent Mousse Content
72 gpm

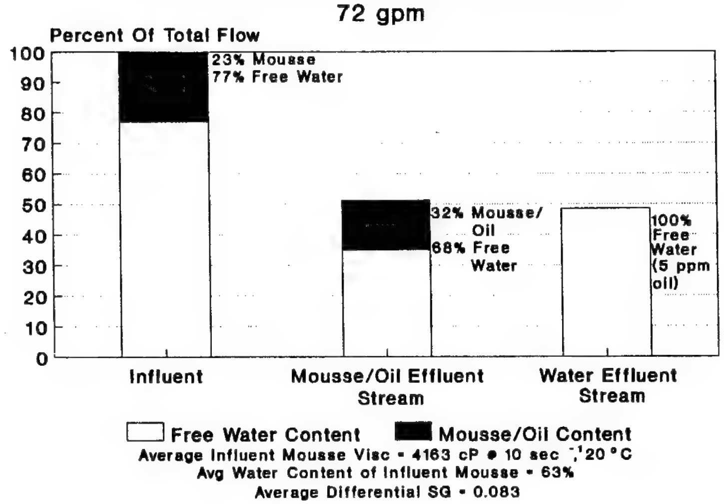


Figure 24d:
Alfa-Laval Mousse Test Series
Test #4: 49% Influent Mousse Content
67 gpm

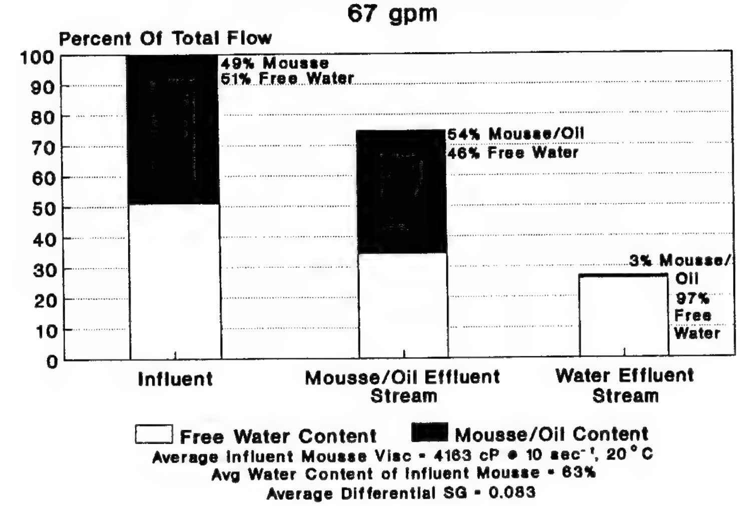


Figure 24e:

Alfa-Laval Mousse Test Series
Test #4a: 50% Influent Mousse Content
57 gpm

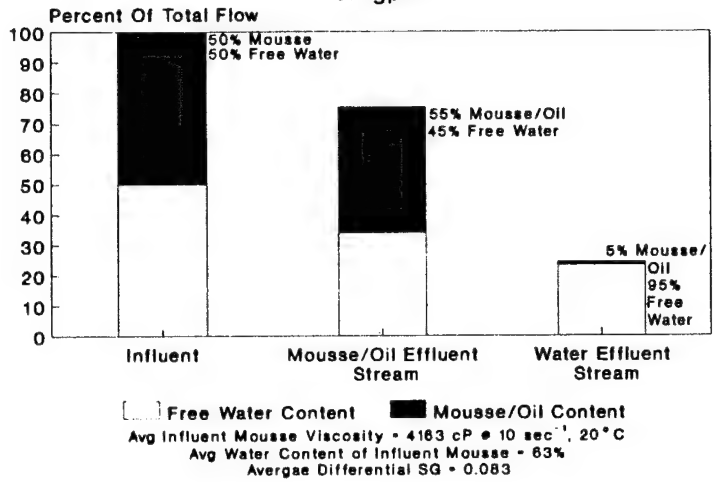


Figure 24f:

Alfa-Laval Mousse Test Series
Test #5: 100% Influent Mousse Content
49 gpm

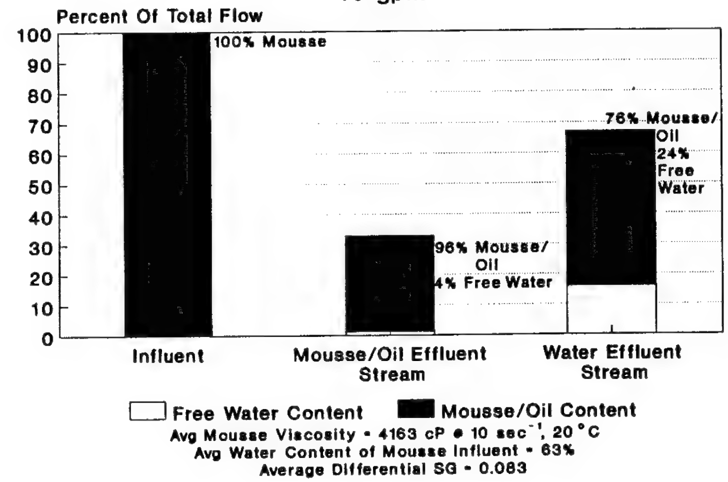
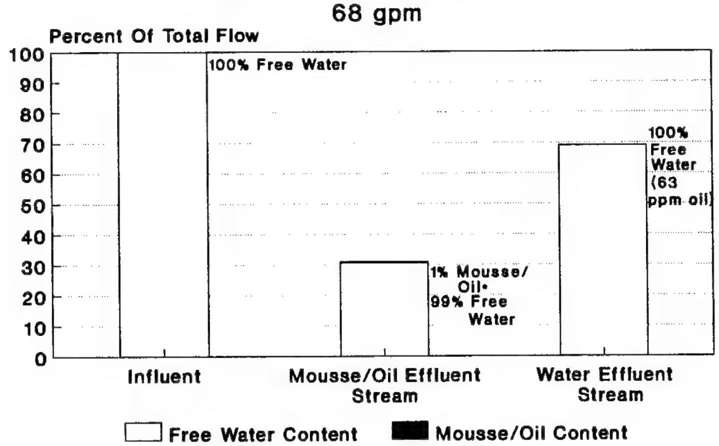


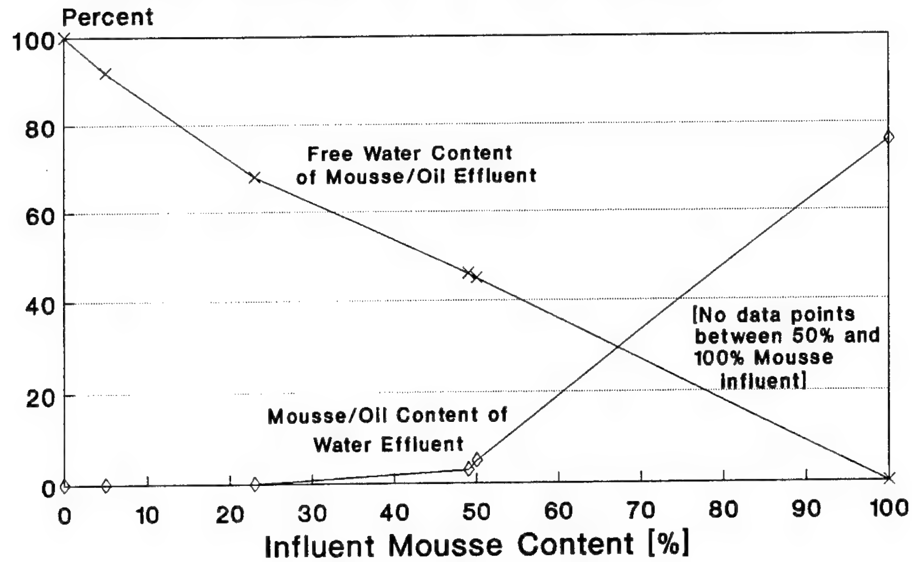
Figure 24g:

Alfa-Laval Mousse Test Series
Test #6: 100% Water Influent
68 gpm



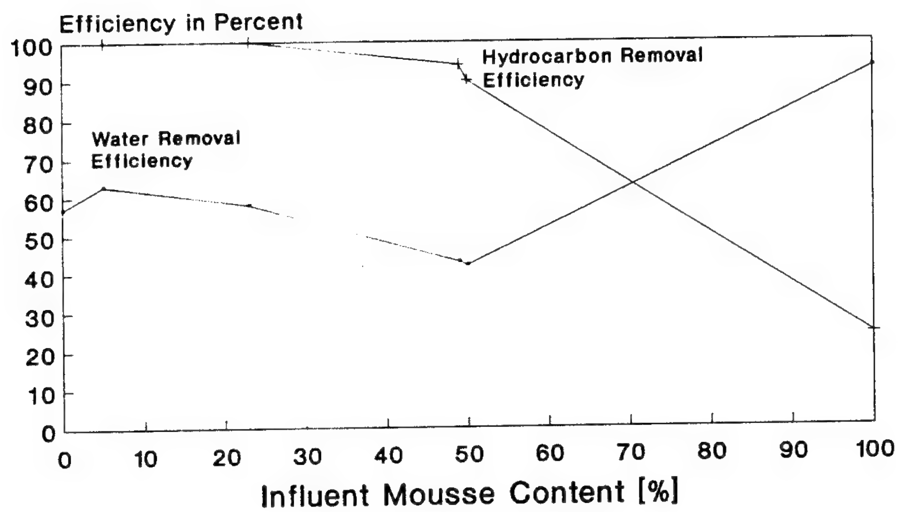
* Assumed to be from residual mousse/oil in test lines.

Figure 25:
Alfa-Laval Mousse Test Series
Effluent Composition vs. Influent Mousse Content



Average Flow Rate = 63 gpm
Avg Infl Mousse Visc = 4163 cP @ 10 sec^{-1}, 20° C, 63% Water
Average Differential SG = 0.083

Figure 26:
Alfa-Laval Mousse Test Series
Efficiency vs. Influent Mousse Content



Average Flow Rate = 63 gpm
Avg Infl Mousse Visc = 4163 cP @ 10 sec^{-1}, 20 °C, 63% Water
Average Differential SG = 0.083

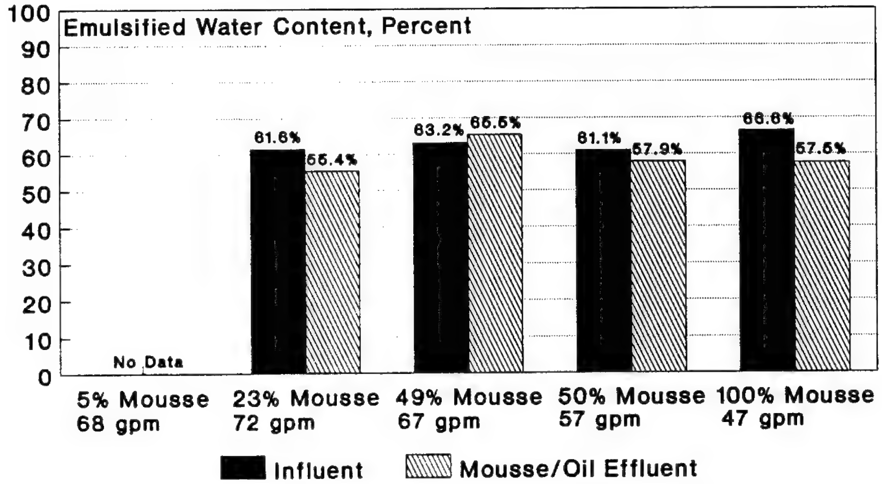


Figure 27:
Alfa-Laval Mousse Test Series
Emulsified Water Content
Before and After Separation

Average Flow Rate = 63 gpm
Avg Infl Mousse Visc = 4163 cP @ 10 sec^{-1}, 20 °C, 63% Water
Average Differential SG = 0.083

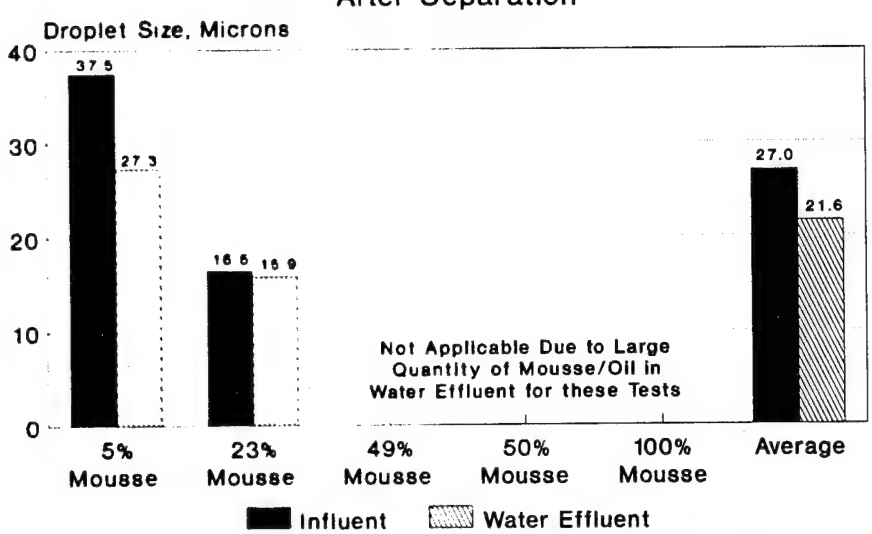


Figure 28:
Alfa-Laval Mousse Test Series
Change in Mean Oil Droplet Size
After Separation

Avg Infl Mousse Visc = 4163 cP @ 10 sec^{-1}, 20 °C, 63% Water
Average Differential SG = 0.083

Figure 29:

Alfa-Laval Mousse Test Series
Influent and Effluent Line Pressure
vs. Time

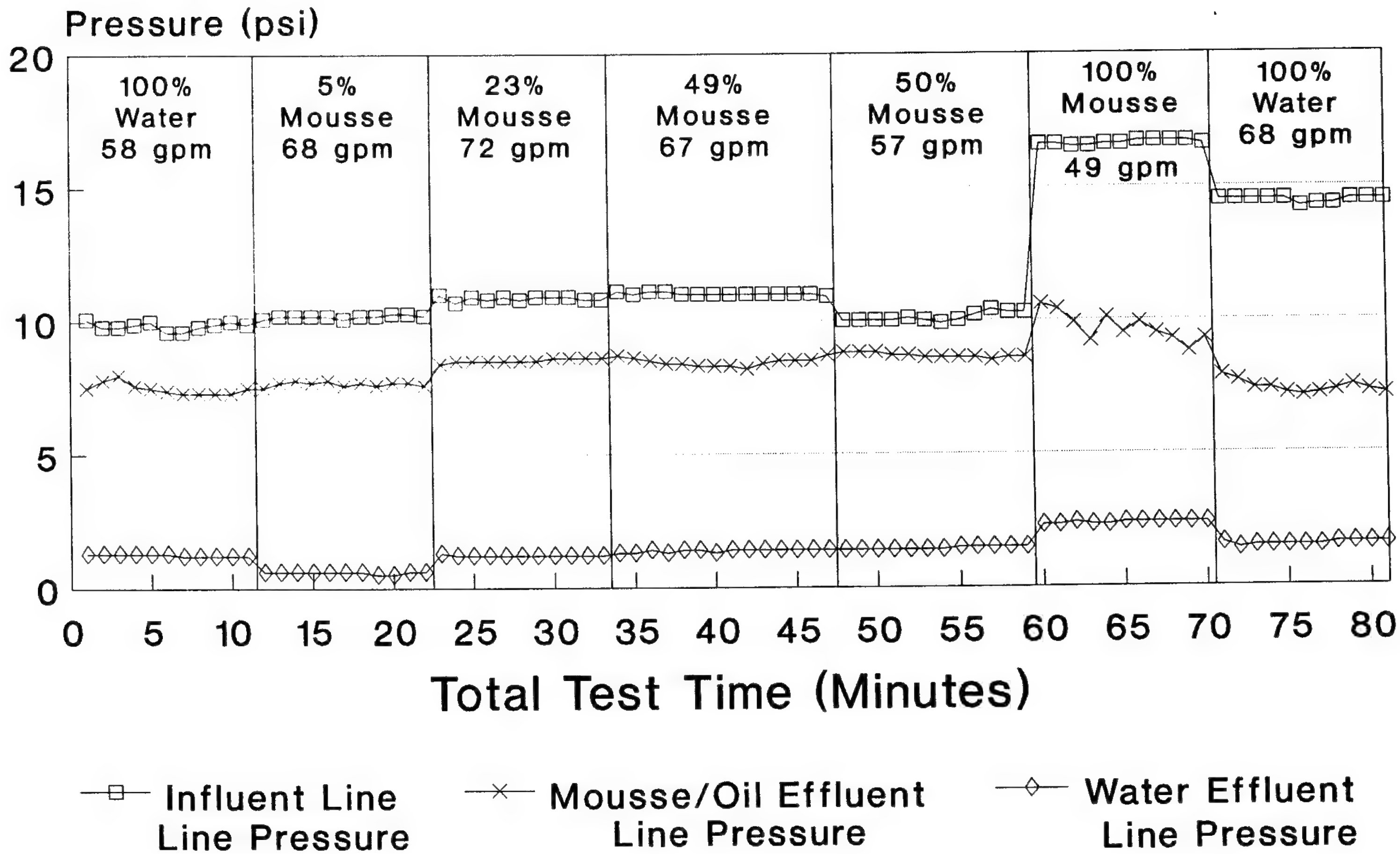


Figure 30:

Impact of Mousse on Alfa-Laval: Mousse/Oil Content in Water Effluent for Crude Oil and Mousse Test Series

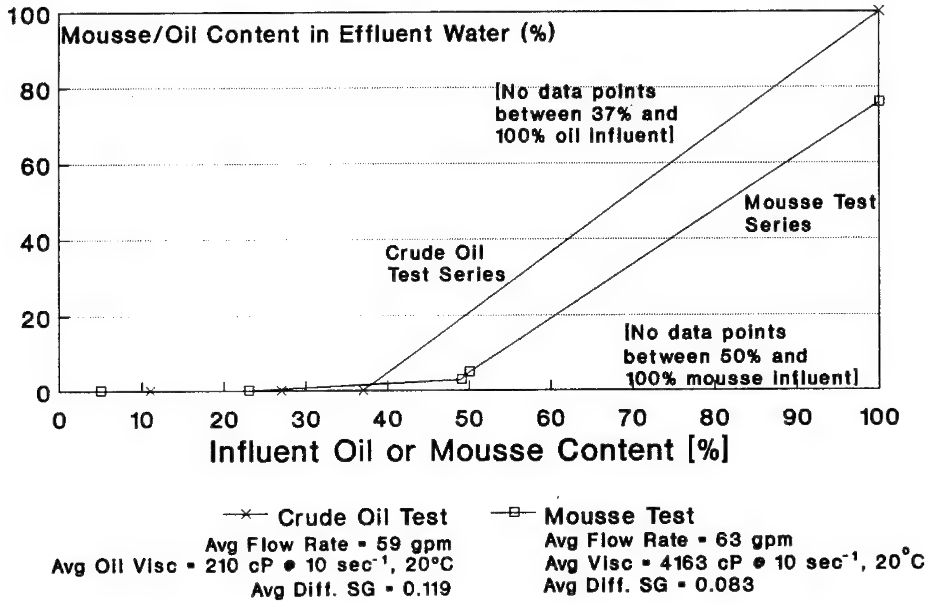


Figure 31:

Impact of Mousse on Alfa-Laval: Comparison of Water in Effluent Mousse/ Oil Stream for Crude Oil and Mousse Test Series

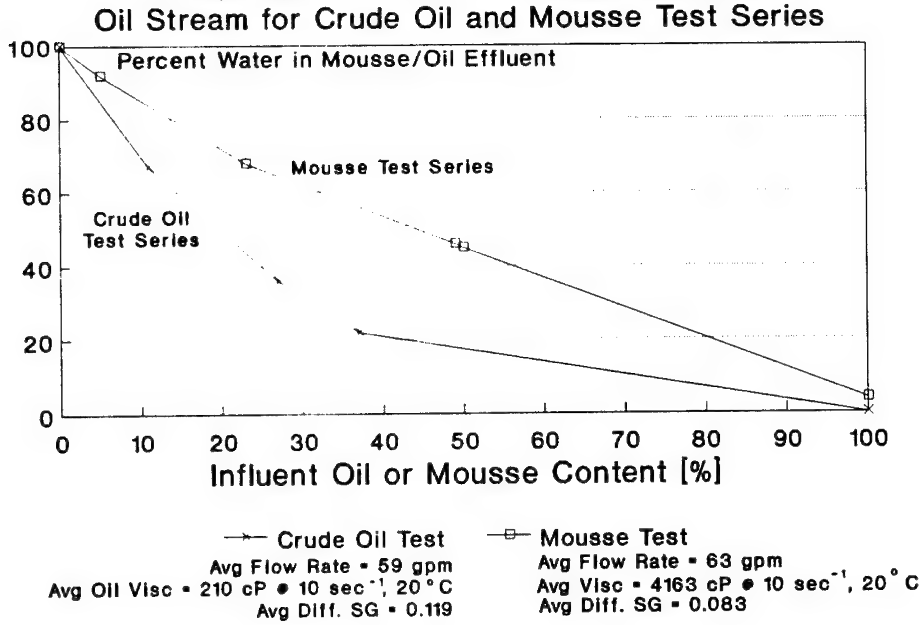


Figure 32:

Impact of Mousse on Alfa-Laval:
Water Removal Efficiency vs. Influent
Mousse/Oil Content for Crude Oil and Mousse Test Series

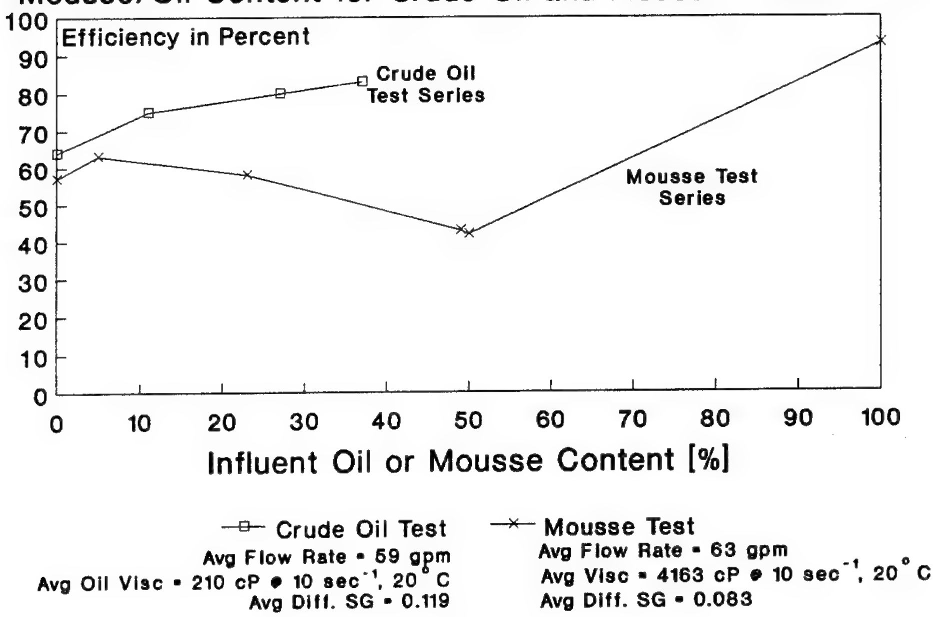


Figure 33:

Impact of Mousse on Alfa-Laval:
Hydrocarbon Removal Efficiency vs. Influent Mousse/
Oil Content for Crude Oil and Mousse Test Series

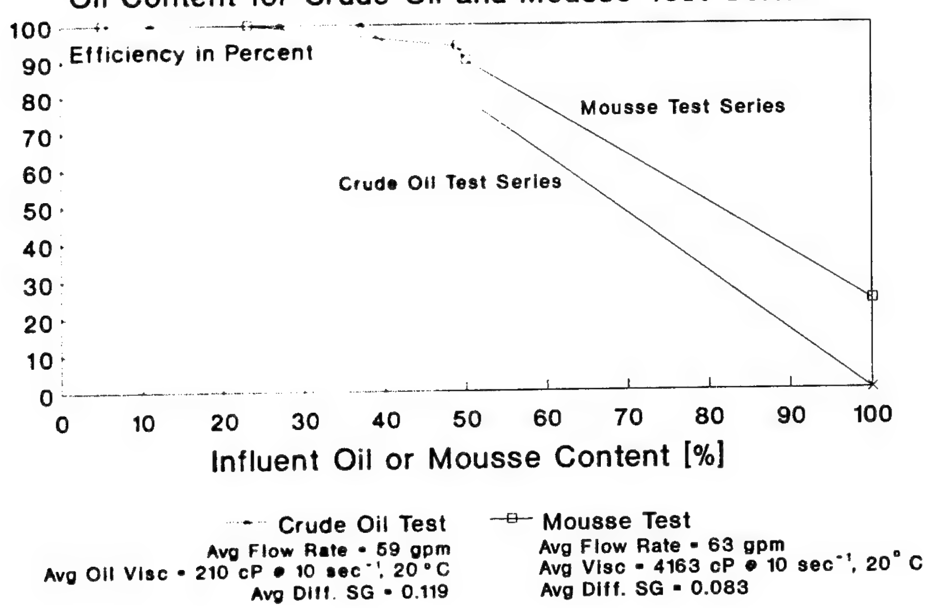


Figure 34a:
Alfa-Laval Mousse With Emulsion Breaker Test Series
Test #1: 100% Water Influent
65 gpm

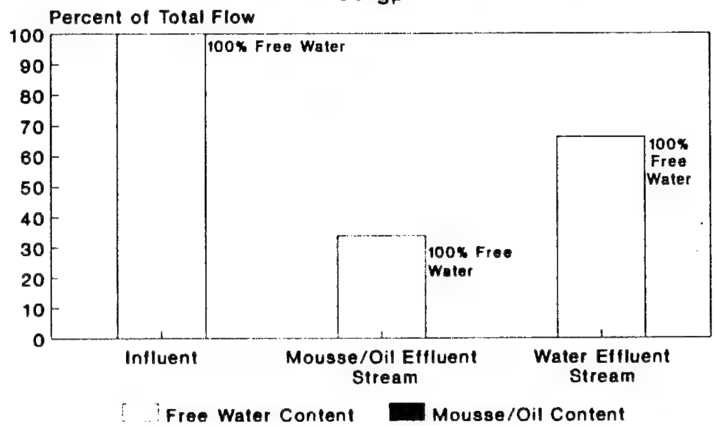


Figure 34b:
Alfa-Laval Mousse With Emulsion Breaker Test Series
Test #2: 3% Influent Mousse Content
66 gpm

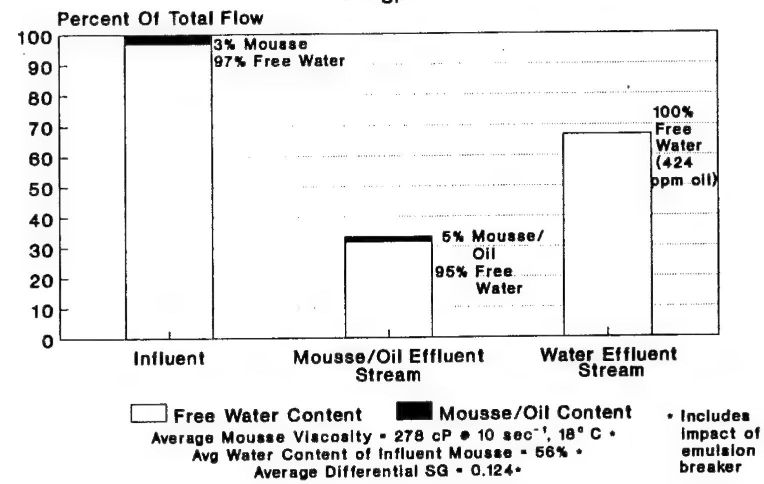


Figure 34c:
Alfa-Laval Mousse With Emulsion Breaker Test Series
Test #3: 15% Influent Mousse Content
57 gpm

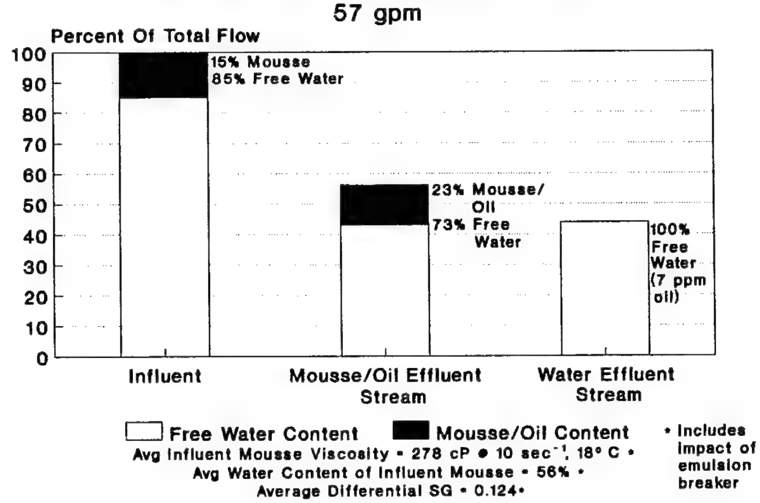


Figure 34d:
Alfa-Laval Mousse With Emulsion Breaker Test Series
Test #4: 23% Influent Mousse Content
78 gpm

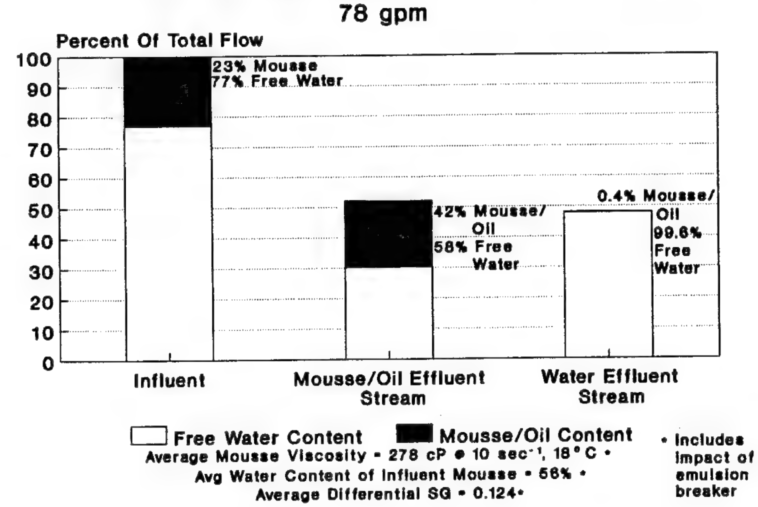


Figure 34e:

Alfa-Laval Mousse With Emulsion Breaker Test Series
Test #5: 100% Mousse Influent
75 gpm

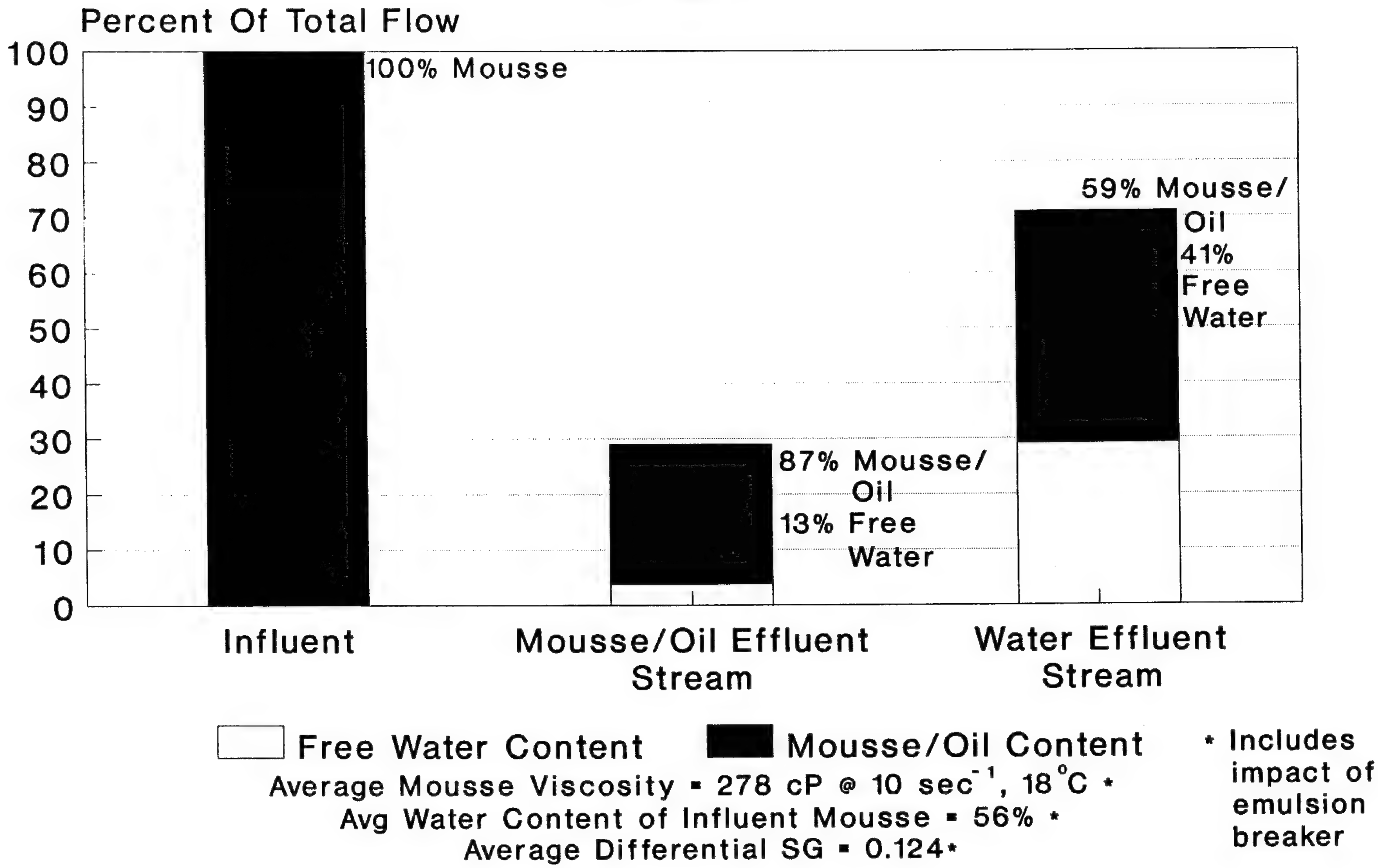
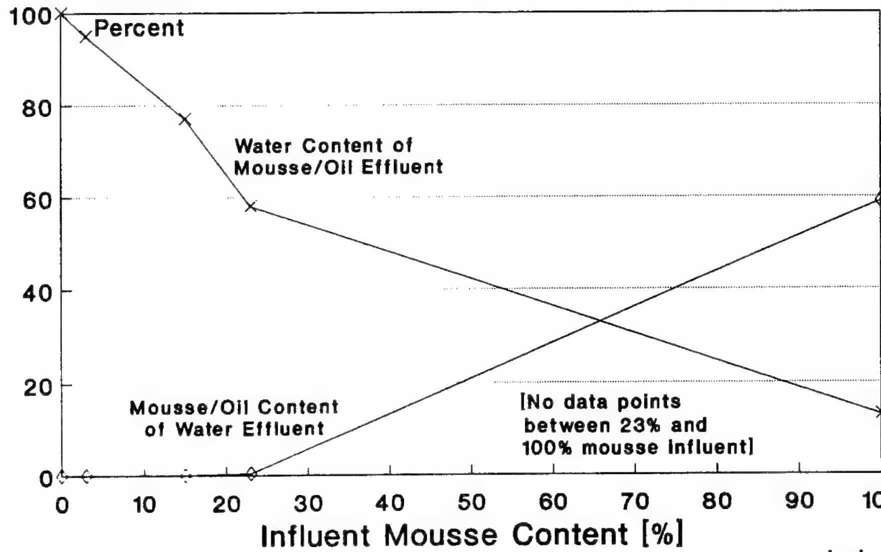


Figure 35:

Alfa-Laval Mousse With Emulsion Breaker Test Series
Effluent Composition vs. Influent Mousse Content

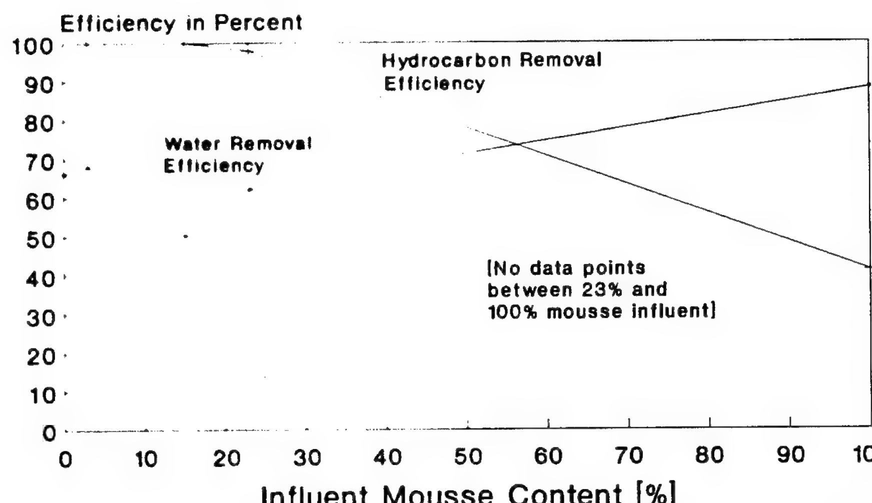


Average Flow Rate = 68 gpm
Avg Infl Mousse Visc. = 278 cP @ 10 sec^{-1}, 18 °C, 56% Water*
Average Differential SG = 0.124*

* includes impact of emulsion breaker

Figure 36:

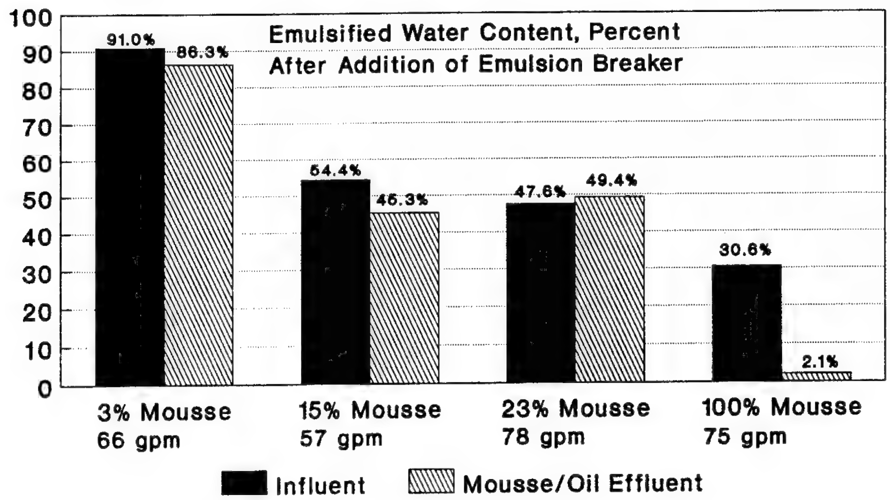
Alfa-Laval Mousse With Emulsion Breaker Test Series
Efficiency vs. Influent Mousse Content



Average Flow Rate = 68 gpm
Avg Infl Mousse Visc. = 278 cP @ 10 sec^{-1}, 18 °C, 56% Water*
Average Differential SG = 0.124*

* includes impact of emulsion breaker

Figure 37:
Alfa-Laval Mousse With Emulsion Breaker Test Series
Emulsified Water Content
Before and After Separation



Average Flow Rate = 68 gpm
Avg Infl Mousse Visc. = 278 cP @ 10 sec^{-1}, 18 °C, 56% Water*
Average Differential SG = 0.124*

* includes impact of emulsion breaker

Figure 38:
Alfa-Laval Mousse With Emulsion Breaker Test Series: Impact of Emulsion Breaker on Viscosity

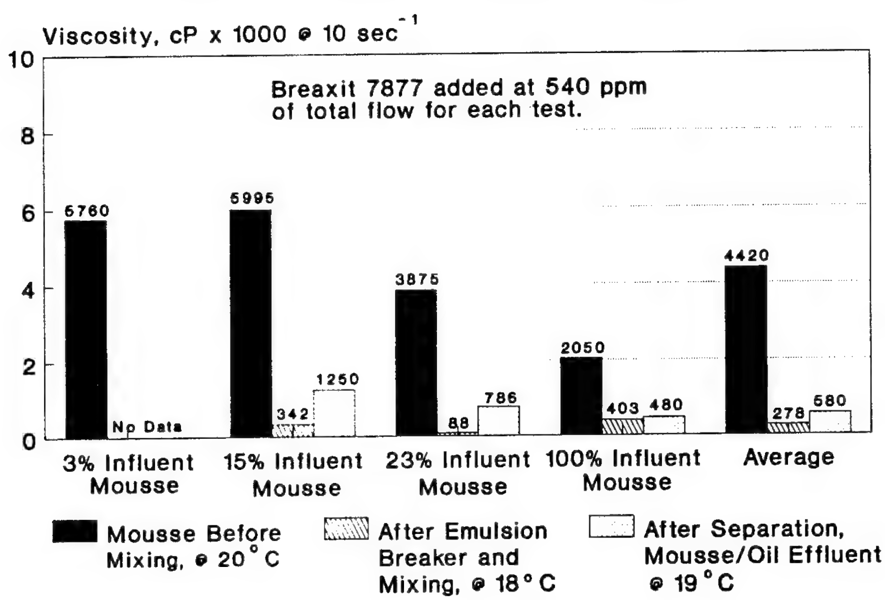


Figure 39:

Alfa-Laval Mousse With Emulsion Breaker Test Series
Change in Mean Oil Droplet Size
After Separation

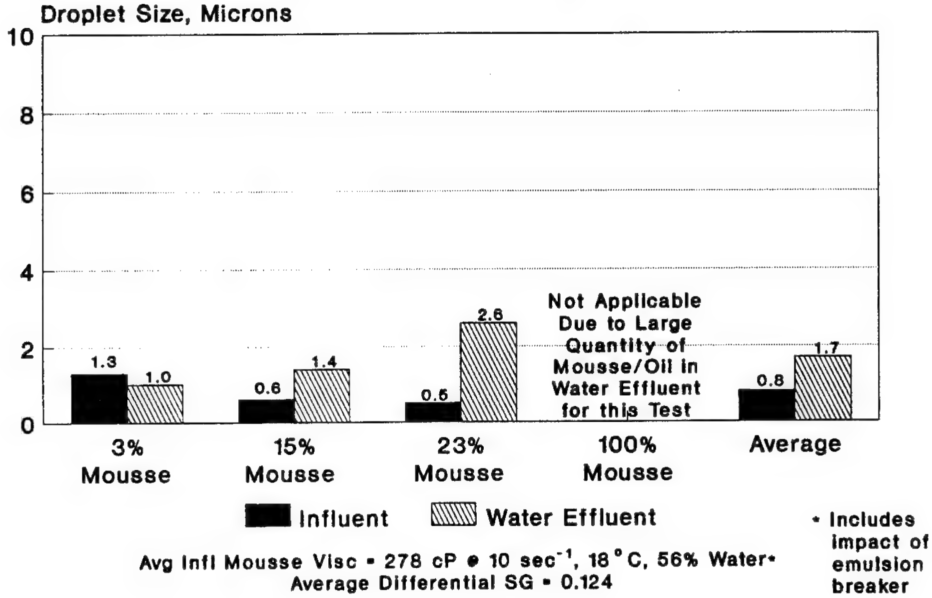
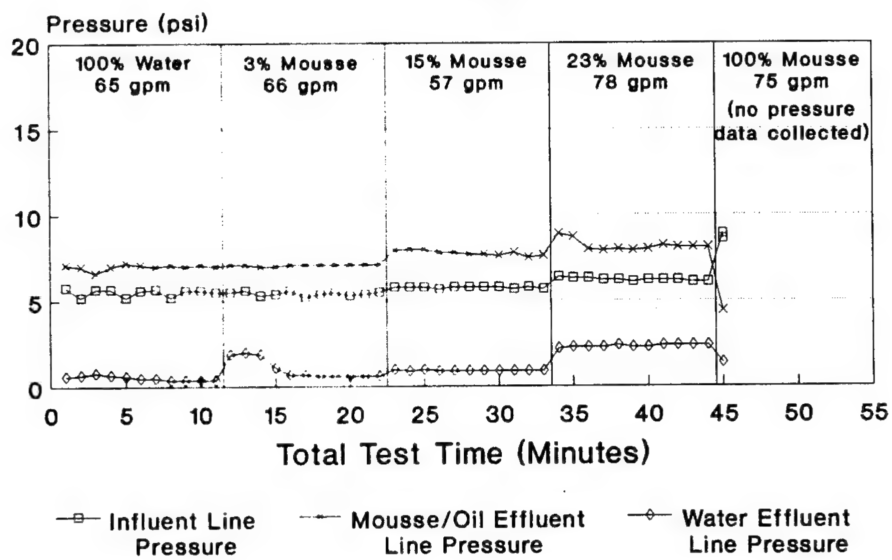


Figure 40:

Alfa-Laval Mousse With Emulsion Breaker Test Series
Influent and Effluent Line Pressure
vs. Time



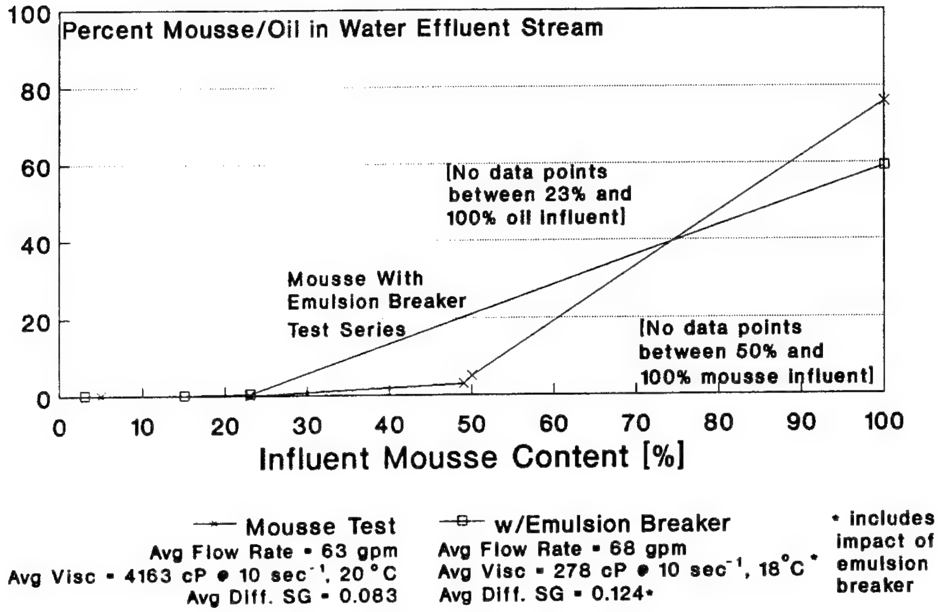


Figure 41:
Impact of Emulsion Breaker on Alfa-Laval:
Effluent Water Mousse/Oil Content for Mousse and
Mousse With Emulsion Breaker Test Series

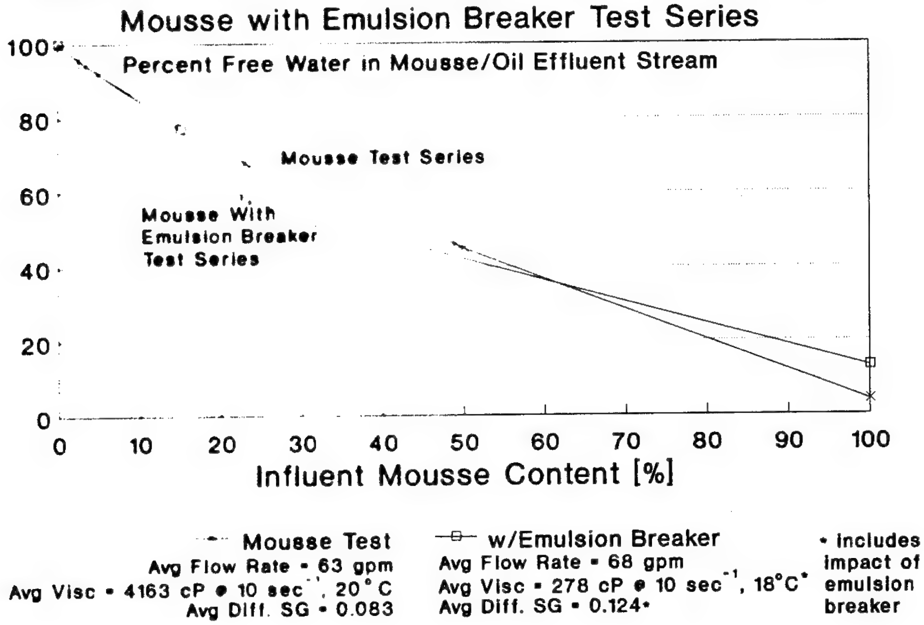
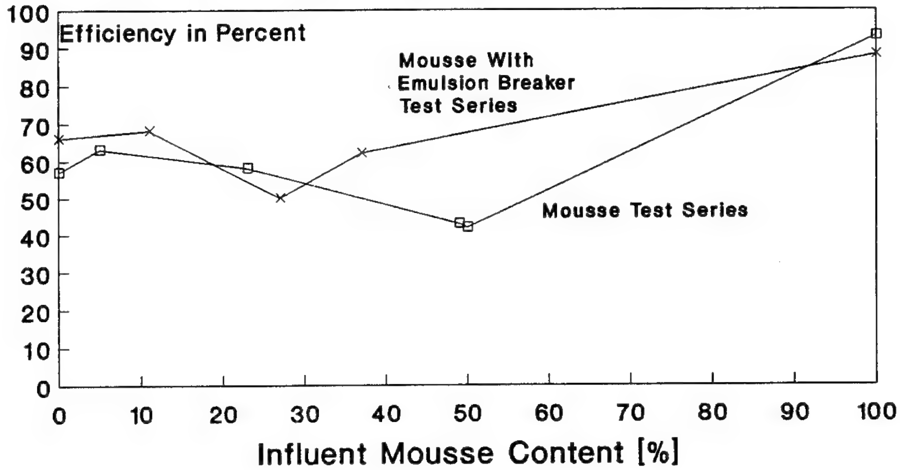


Figure 42:
Impact of Emulsion Breaker on Alfa-Laval:
Water Content of Effluent Mouse/Oil for Mousse and
Mousse with Emulsion Breaker Test Series

Figure 43:

Impact of Emulsion Breaker on Alfa-Laval: Water Removal Efficiency Comparison for Mousse and Mousse With Emulsion Breaker Test Series



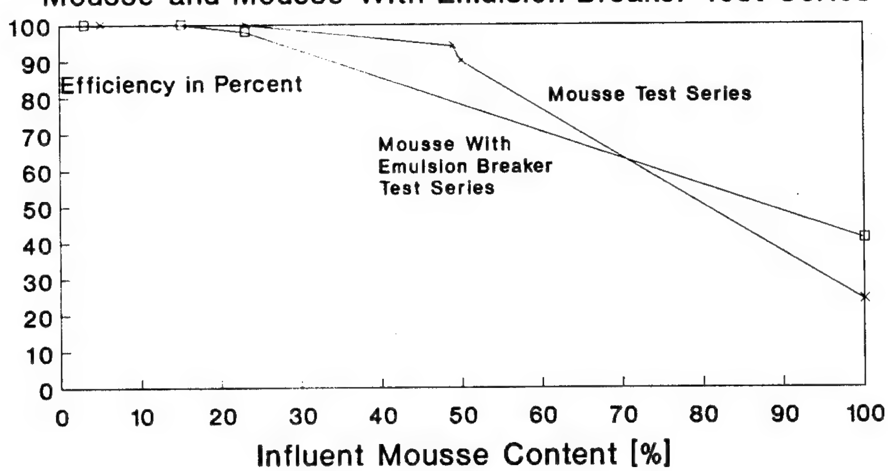
Mousse Test
Avg Flow Rate = 63 gpm
Avg Visc = 4163 cP @ 10 sec^{-1}, 20 °C
Avg Diff. SG = 0.083

w/Emulsion Breaker
Avg Flow Rate = 68 gpm
Avg Visc = 278 cP @ 10 sec^{-1}, 18°C*
Avg Diff. SG = 0.124*

* includes impact of emulsion breaker

Figure 44:

Impact of Emulsion Breaker on Alfa-Laval: Hydrocarbon Removal Efficiency Comparison for Mousse and Mousse With Emulsion Breaker Test Series



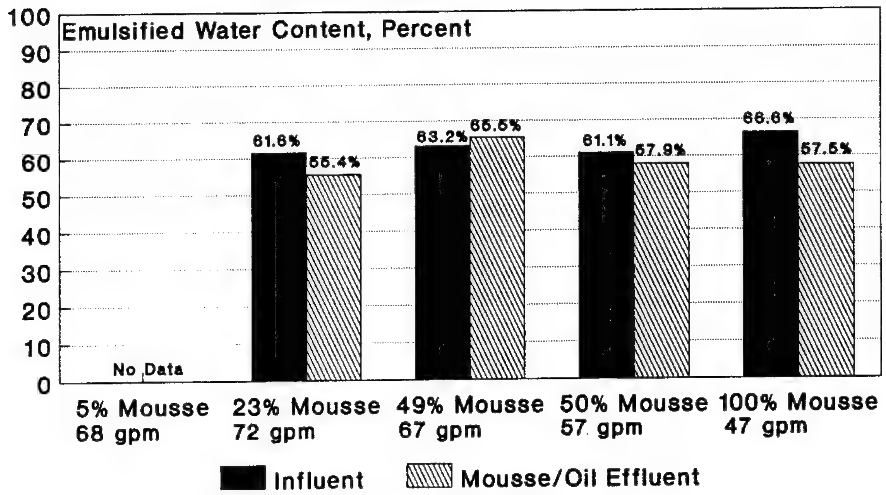
Mousse Test
Avg Flow Rate = 63 gpm
Avg Visc = 4163 cP @ 10 sec^{-1}, 20 °C
Avg Diff. SG = 0.083

w/Emulsion Breaker
Avg Flow Rate = 68 gpm
Avg Visc = 278 cP @ 10 sec^{-1}, 18 °C*
Avg Diff. SG = 0.124*

* includes impact of emulsion breaker

Figure 45:

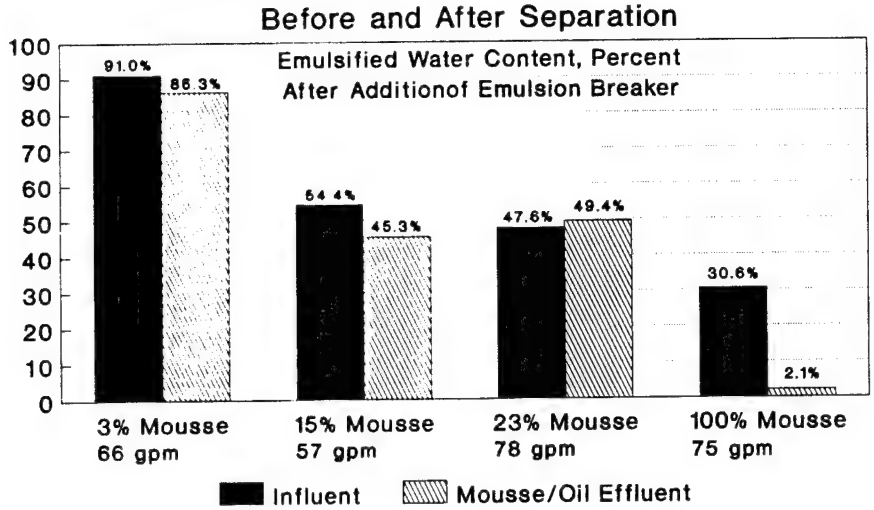
Alfa-Laval Mousse Test Series
Emulsifed Water Content
Before and After Separation



Average Flow Rate = 63 gpm
Avg Infl Mousse Visc = 4163 cP @ 10 sec^{-1}, 20 °C, 63% Water
Average Differential SG = 0.083

Figure 46:

Alfa-Laval Mousse With Emulsion Breaker
Test Series: Emulsified Water Content
Before and After Separation



Average Flow Rate = 68 gpm
Avg Infl Mousse Visc. = 278 cP @ 10 sec^{-1}, 18 °C, 56% Water*
Average Differential SG = 0.124*

* includes impact of emulsion breaker

Figure 47:

Alfa-Laval Debris Test Series
Influent and Effluent Line Pressure vs. Time

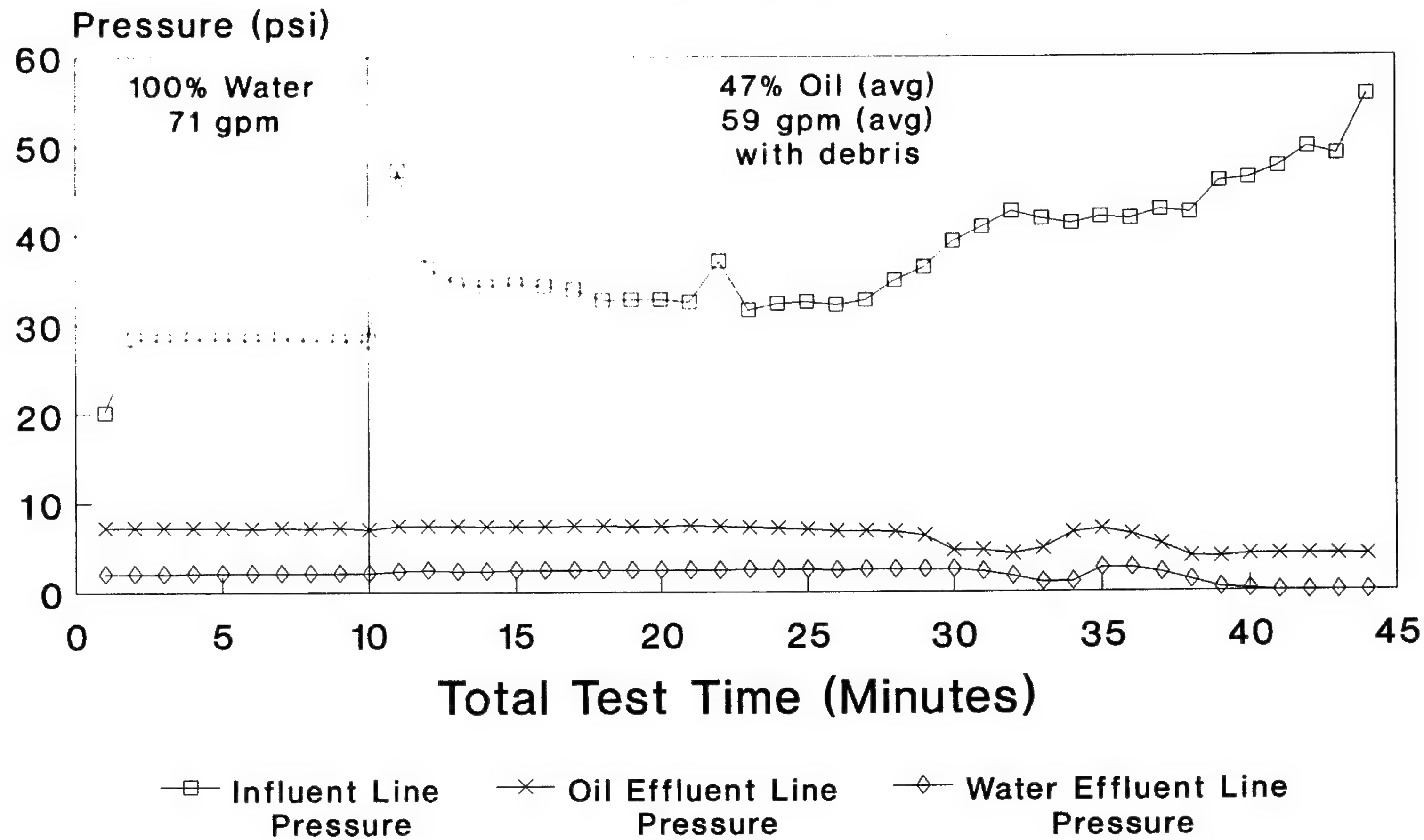


Figure 48a:
Alfa-Laval Debris Test Series
Test #1: 100% Water (no debris)
71 gpm

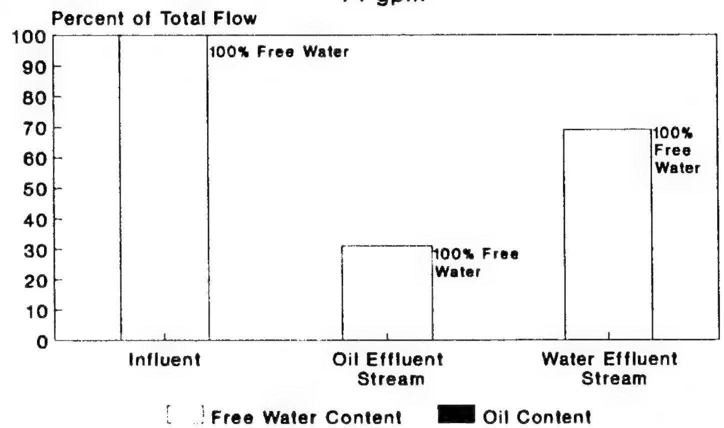
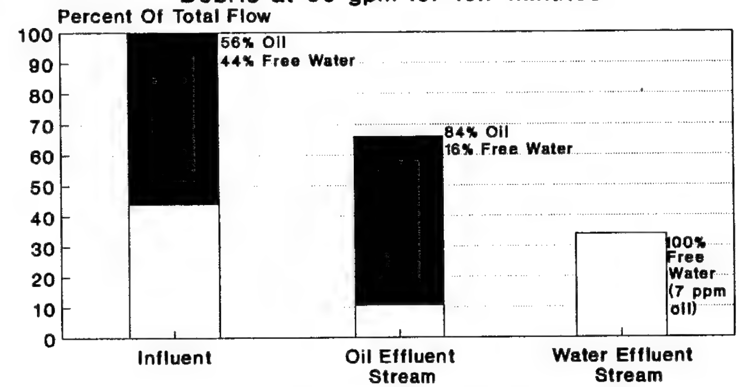
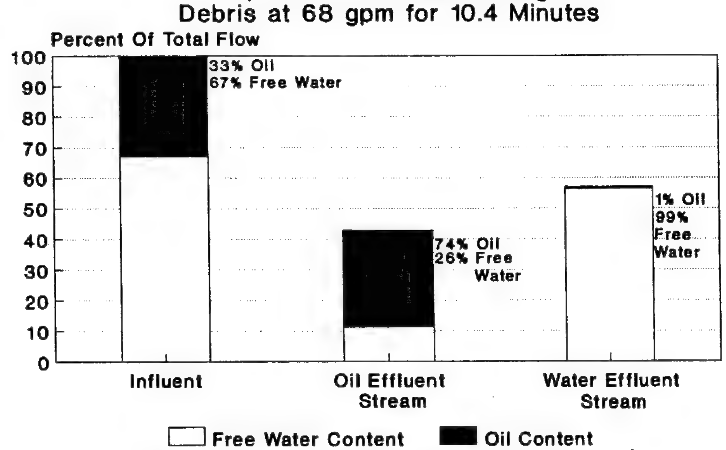


Figure 48b:
Alfa-Laval Debris Test Series
Test #2, Period 1: 56% Oil (avg) with
Debris at 60 gpm for 10.7 Minutes



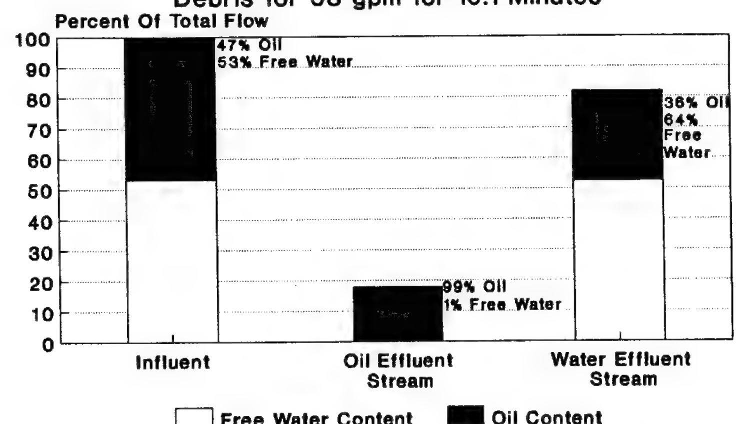
Average Oil Viscosity - 536 cP @ shear rate 10 sec^{-1}, 20° C
Average Differential SG - 0.149

Figure 48c:
Alfa-Laval Debris Test Series
Test #2, Period 2: 33% Oil (avg) with
Debris at 68 gpm for 10.4 Minutes



Average Oil Viscosity - 536 cP @ shear rate - 10 sec^{-1}, 20°C
Average Differential SG - 0.149

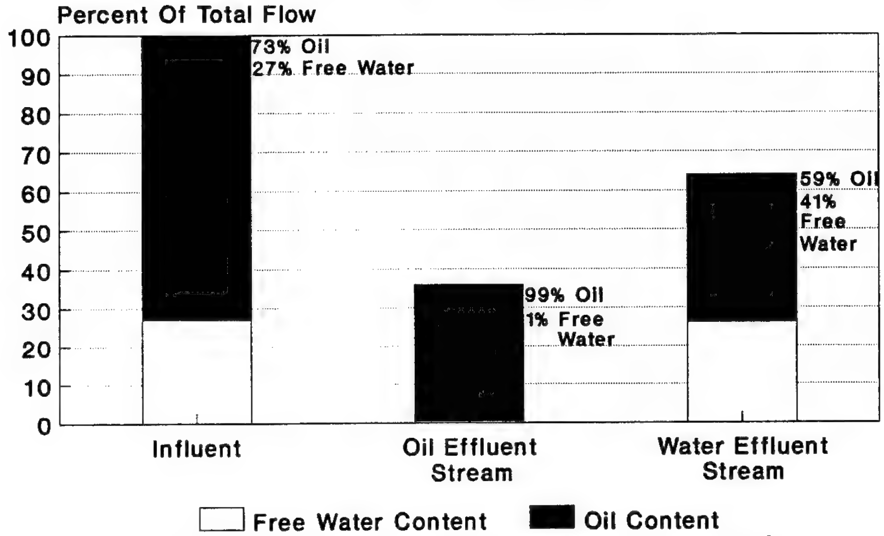
Figure 48d:
Alfa-Laval Debris Test Series
Test #2, Period #3: 47% Oil (avg) with
Debris for 58 gpm for 10.1 Minutes



Average Oil Viscosity - 536 cP @ shear rate - 10 sec^{-1}, 20°C
Average Differential SG - 0.149

Figure 48e:

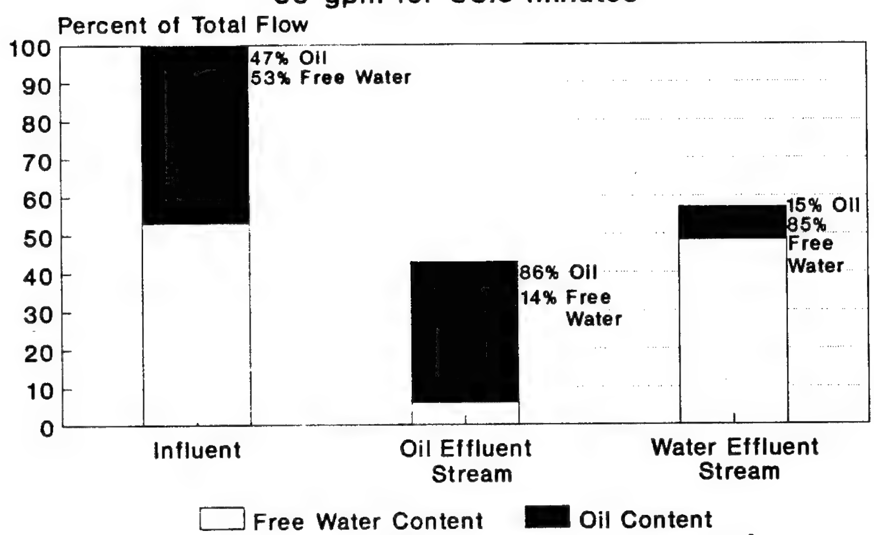
Alfa-Laval Debris Test Series
Test #2, Period #4: 73% Oil (avg) with
Debris for 10 gpm for 2.3 Minutes



Average Oil Viscosity = 536 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.149

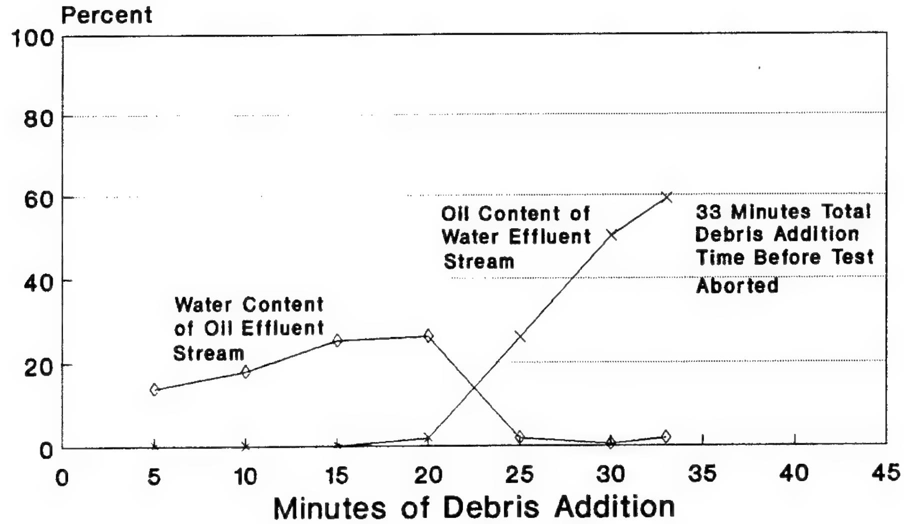
Figure 48f:

Alfa-Laval Debris Test Series
Test #2 Average: 47% Oil with Debris
59 gpm for 33.5 Minutes



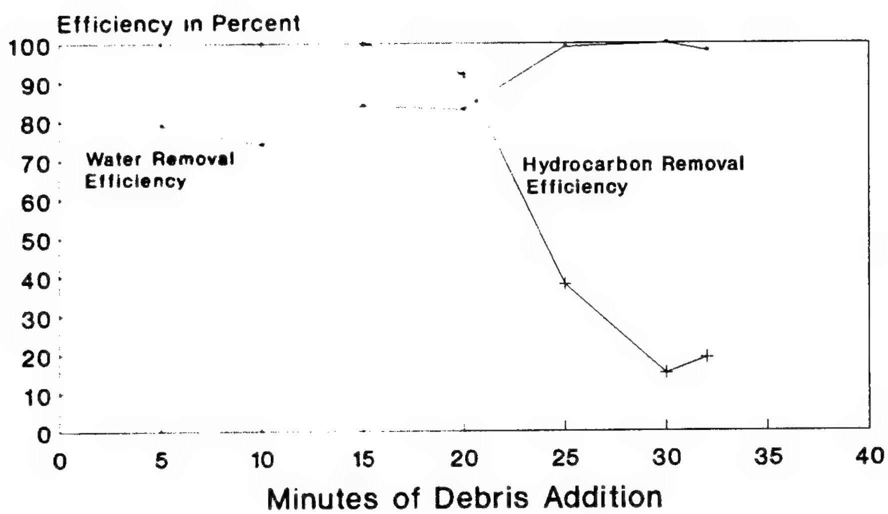
Average Oil Viscosity = 536 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.149

Figure 49:
Alfa-Laval Debris Test Series
Effluent Composition vs. Time



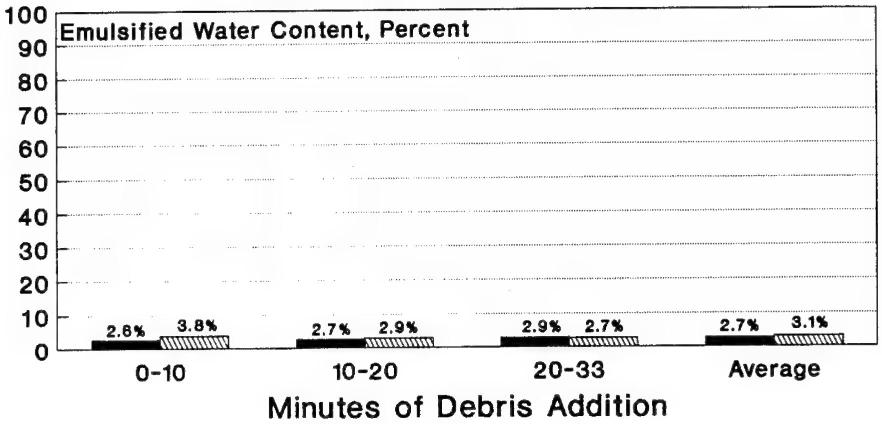
Average Flow Rate = 59 gpm
Average Oil Viscosity = 536 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.149

Figure 50:
Alfa-Laval Debris Test Series
Efficiency vs. Time



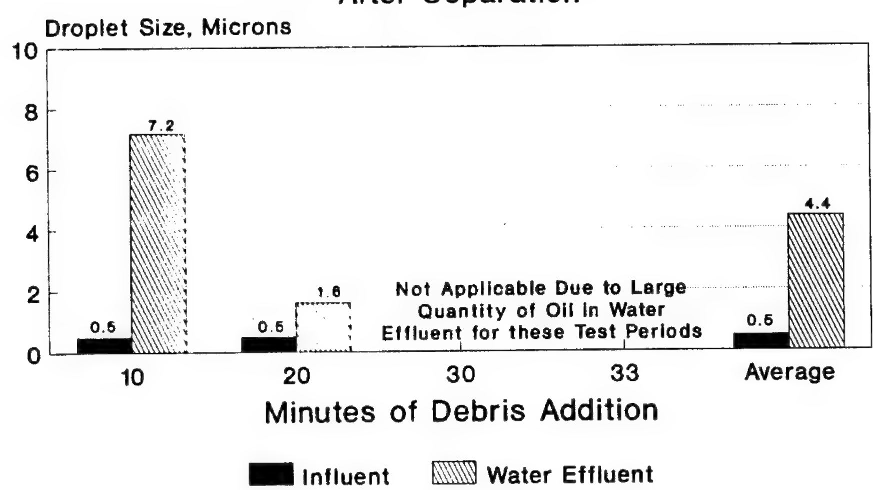
Average Flow Rate = 59 gpm
Average Oil Viscosity = 536 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.149

Figure 51:
Alfa-Laval Debris Test Series
Emulsified Water Content
Before and After Separation



Average Flow Rate = 59 gpm
Average Influent Oil Content = 47%
Average Oil Viscosity = 536 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.149

Figure 52:
Alfa-Laval Debris Test Series
Change in Mean Oil Droplet Size
After Separation



Average Oil Viscosity = 536 cP @ shear rate = 10 sec^{-1}, 20°C
Average Flow Rate = 59 gpm
Average Influent Oil Content = 47%
Average Differential SG = 0.149

Figure 53:

Alfa-Laval Performance Comparison
Crude Oil and Debris Test Series

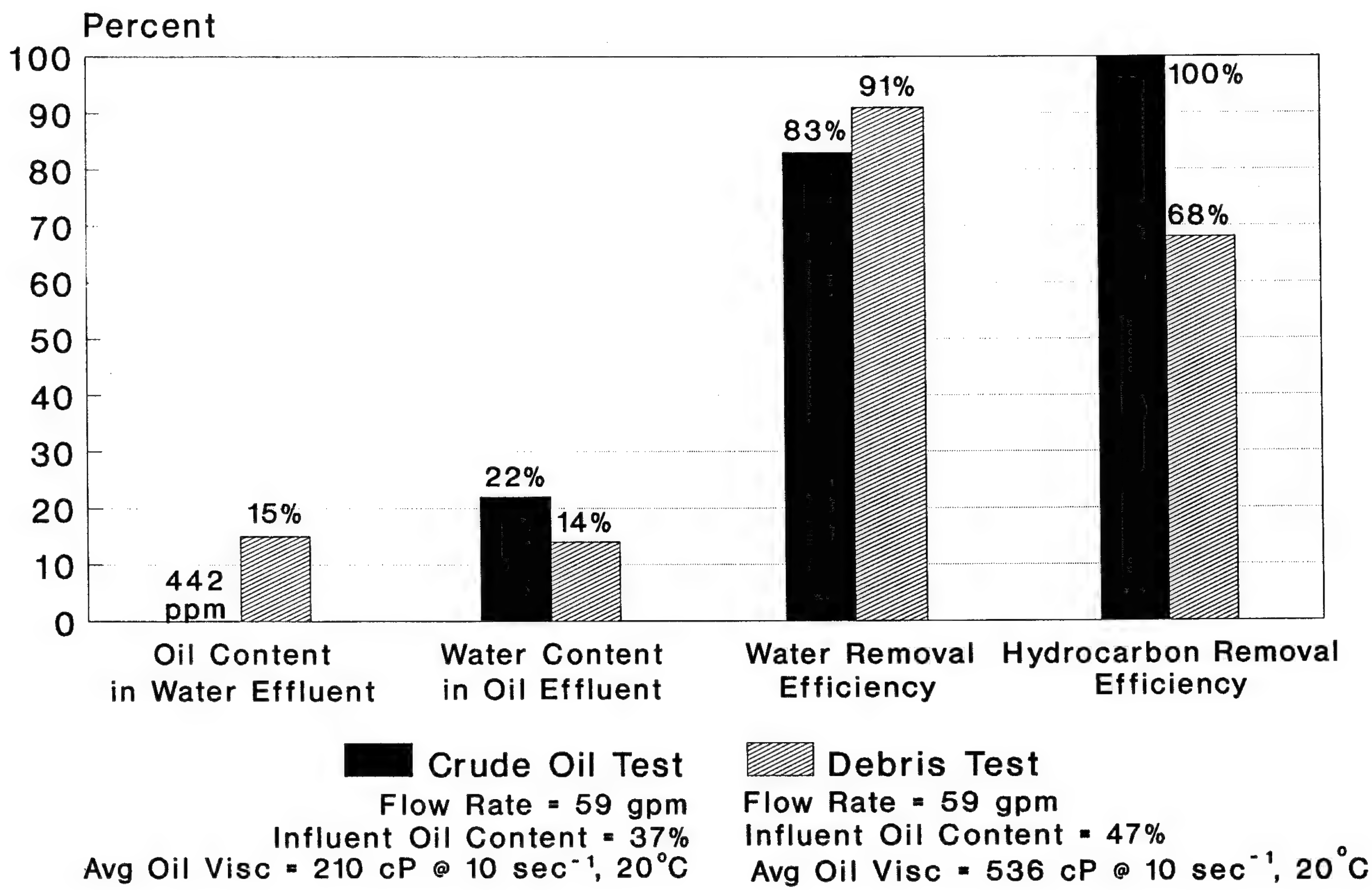


Figure 54: Surge Tank

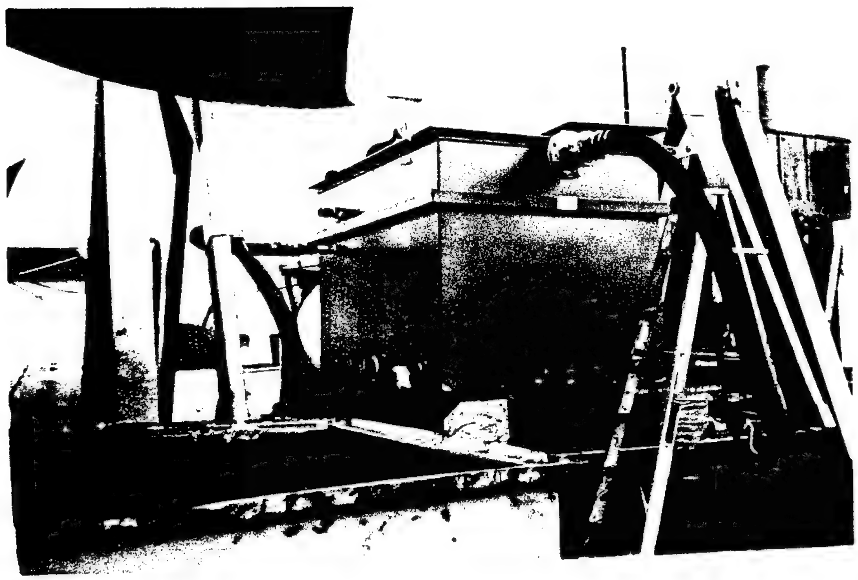


Figure 55: Test Facility Set-Up for Surge Tank

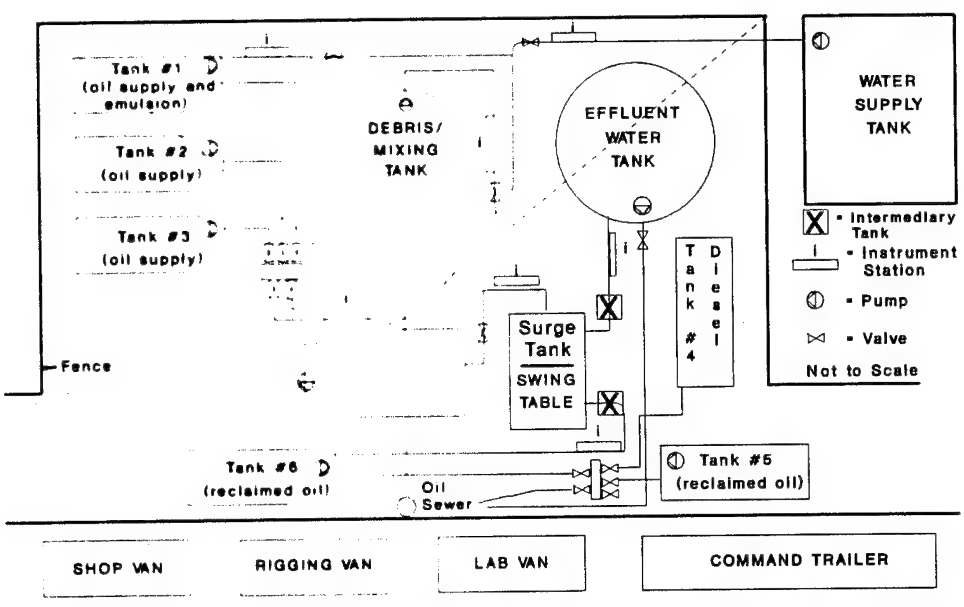


Figure 56a:
Surge Tank Crude Oil Test Series
Test #1: 100% Water Influent
244 gpm

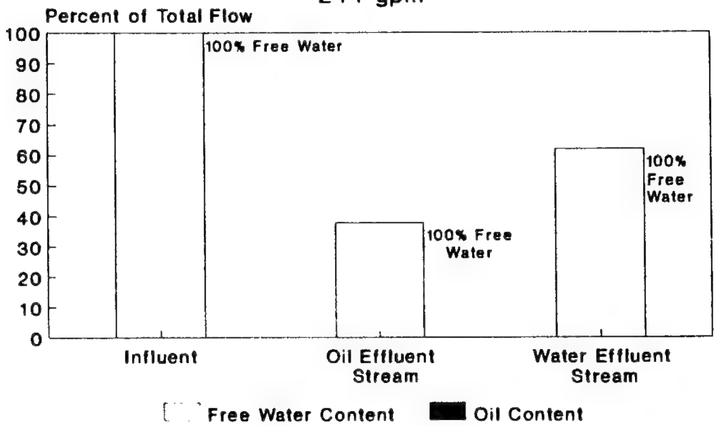


Figure 56b:
Surge Tank Crude Oil Test Series
Test # 2: 5% Influent Oil Content
230 gpm

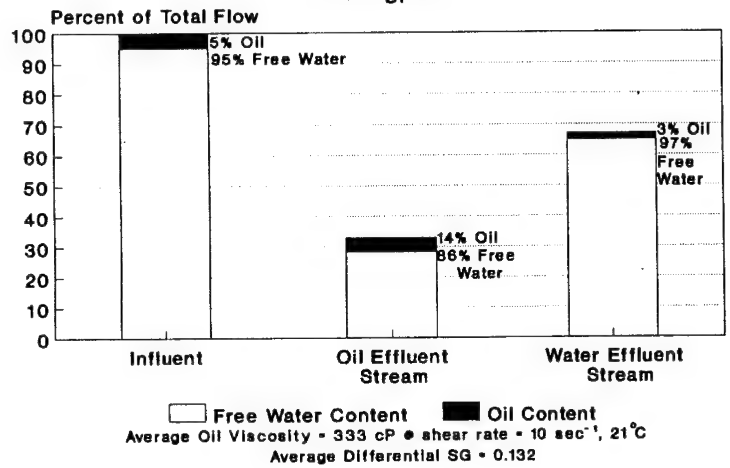


Figure 56c:
Surge Tank Crude Oil Test Series
Test #3: 25% Influent Oil Content
271 gpm

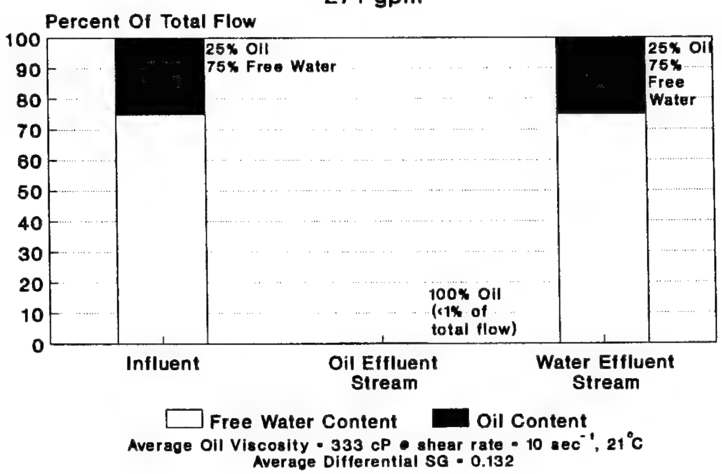


Figure 56d:
Surge Tank Crude Oil Test Series
Test #4: 51% Influent Oil Content
238 gpm

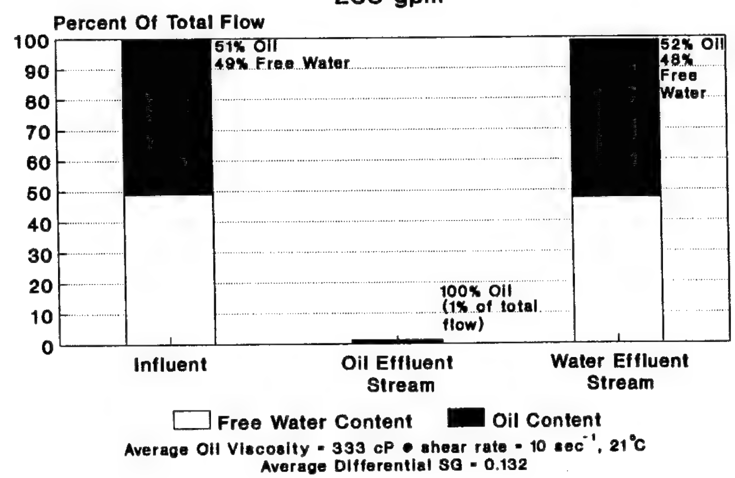


Figure 56e:
Surge Tank Crude Oil Test Series
Test #6: 100% Water Influent
260 gpm

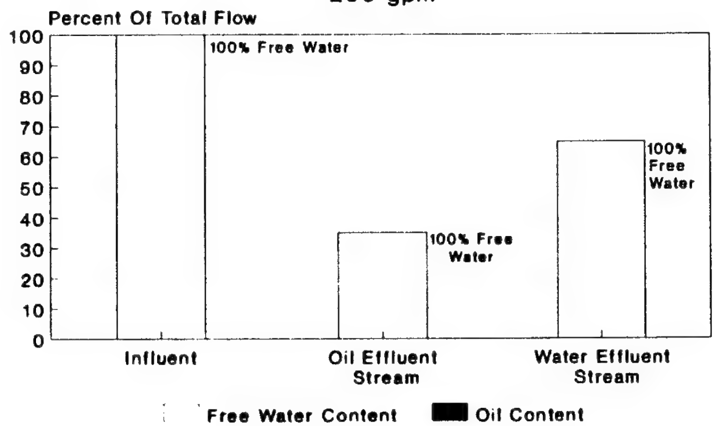


Figure 56f:
Surge Tank Crude Oil Test Series
Test #7: 6% Influent Oil Content, 50% Capacity
124 gpm

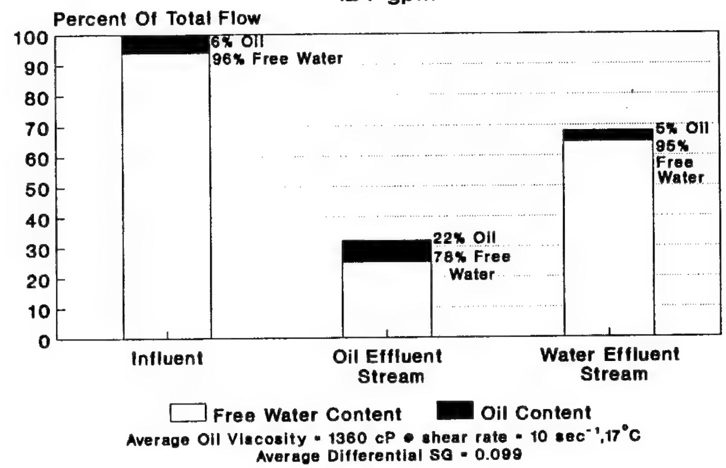


Figure 56g:
Surge Tank Crude Oil Test Series
Test #8: 4% Influent Oil Content, 30% Capacity
76 gpm

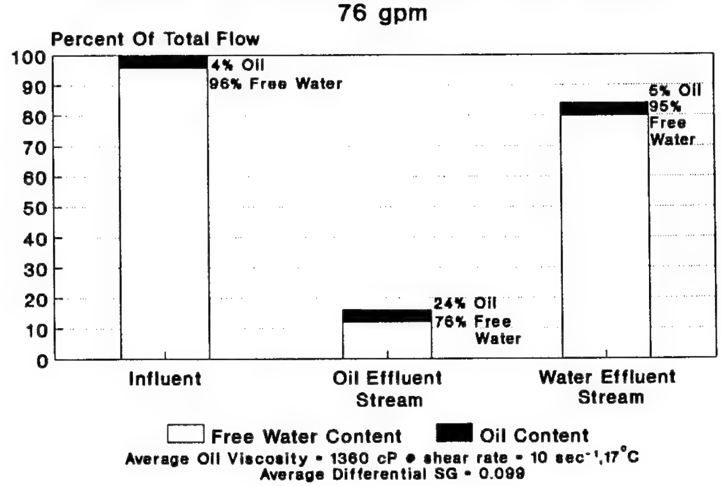
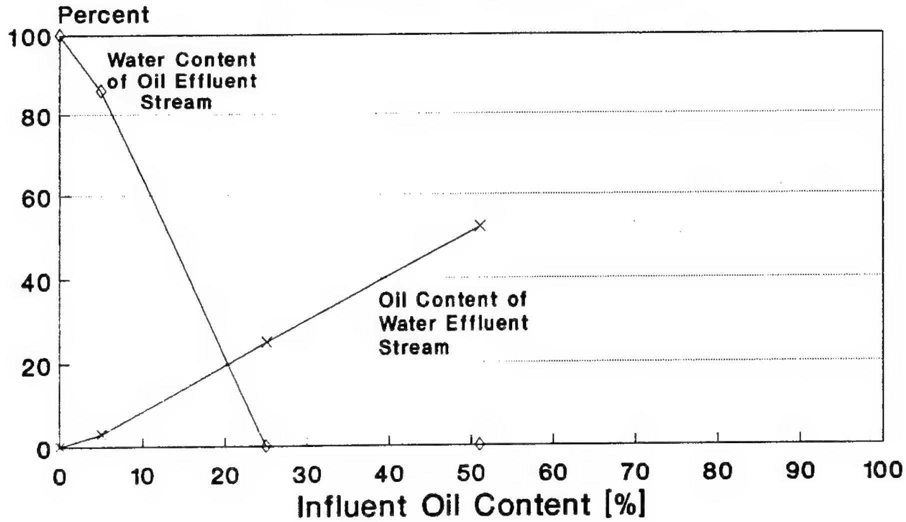


Figure 57:

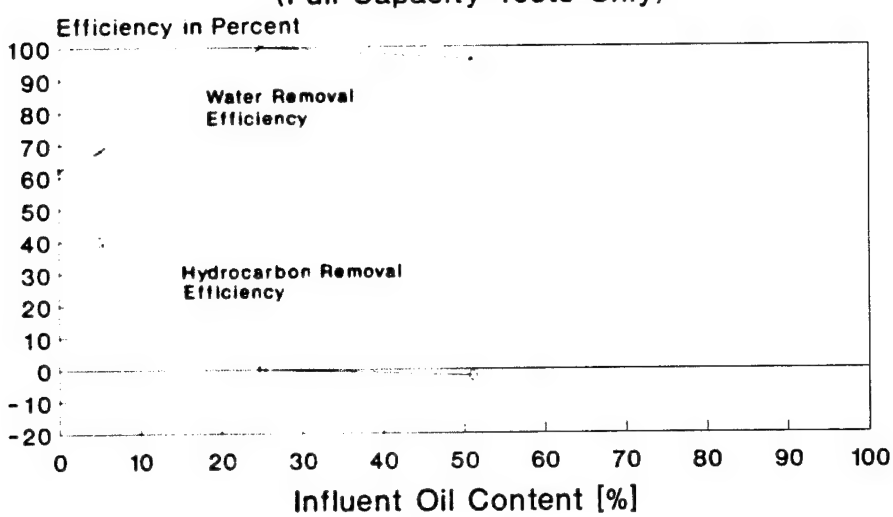
Surge Tank Crude Oil Test Series
Effluent Composition vs. Influent Oil Content
(Full Capacity Tests Only)



Average Flow Rate = 249 gpm
Average Oil Viscosity = 333 cP @ shear rate = 10^{-1}, 21°C
Average Differential SG = 0.132

Figure 58:

Surge Tank Crude Oil Test Series
Efficiency vs. Influent Oil Content
(Full Capacity Tests Only)



Average Flow Rate = 249 gpm
Average Oil Viscosity = 333 cP @ shear rate = 10 sec^{-1}, 21°C
Average Differential SG = 0.132

Figure 59:

Surge Tank Crude Oil Test Series
Emulsified Water Content Before and After Separation

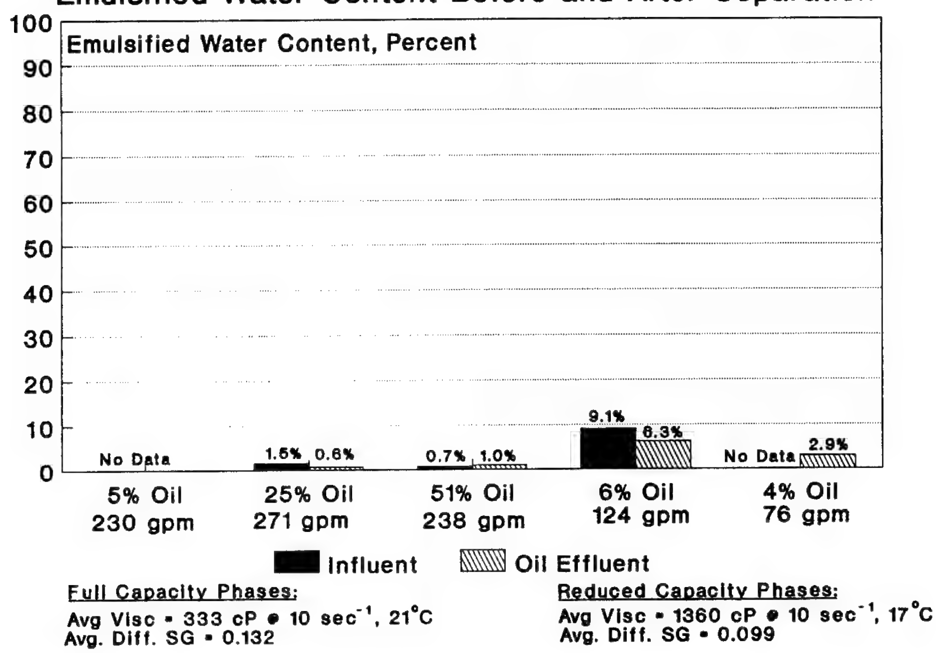


Figure 60:

Surge Tank Crude Oil Test Series
Influent Line Pressure vs. Time

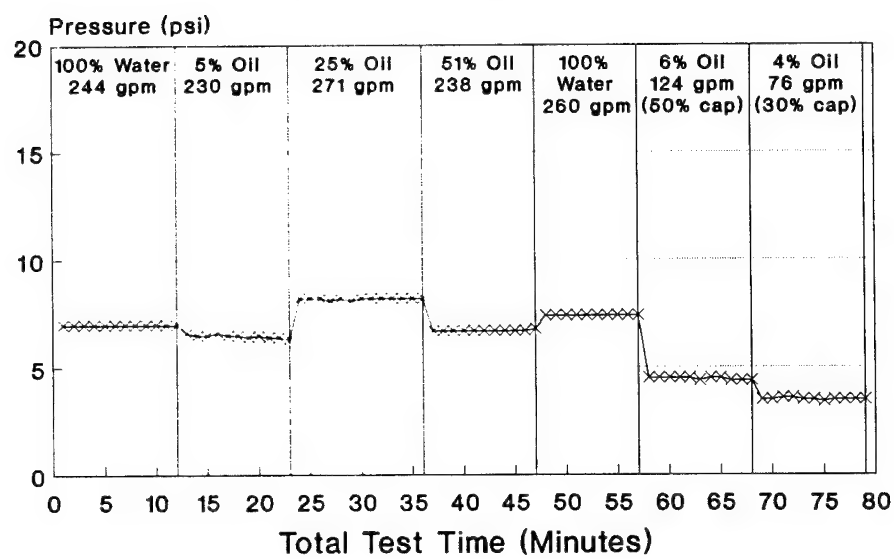


Figure 61:

Surge Tank Crude Oil Test Series
Impact of Reduced Influent Flow Rate

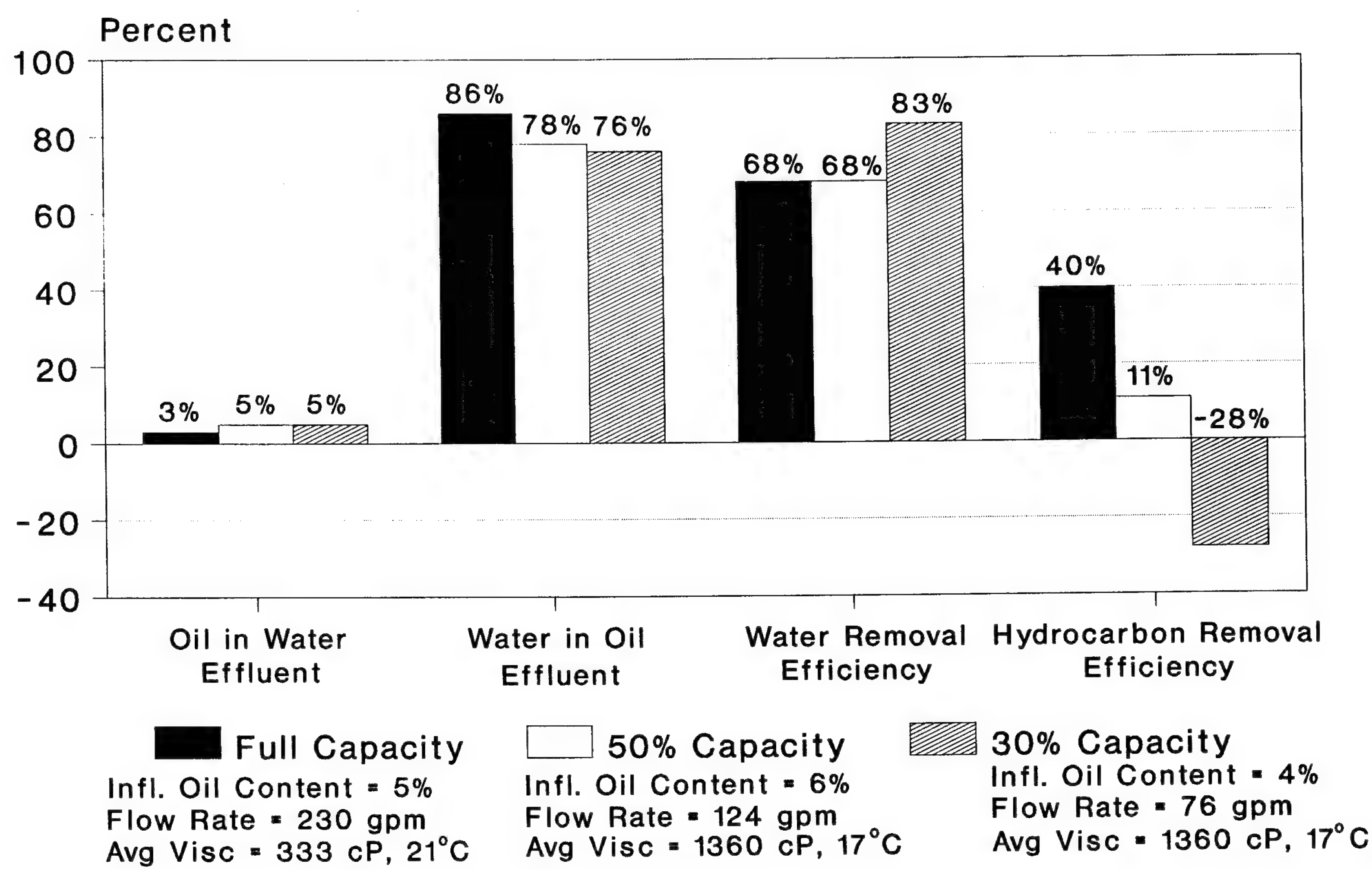


Figure 62a:
Surge Tank Sea Motion Test Series
Test #1: 100% Water
249 gpm

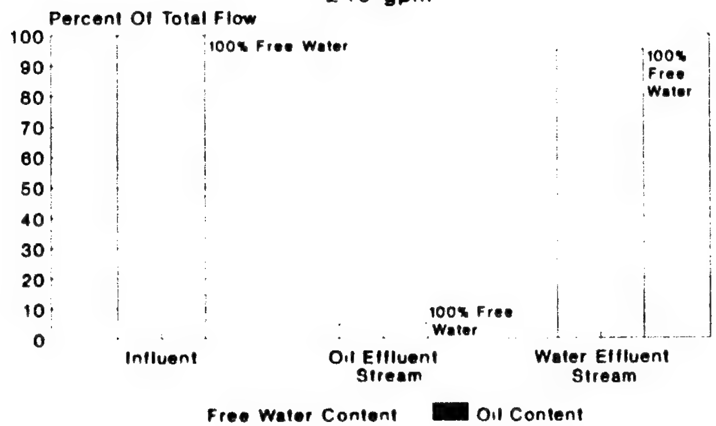


Figure 62b:
Surge Tank Sea Motion Test Series
Test #2: 18% Influent Oil Content
285 gpm

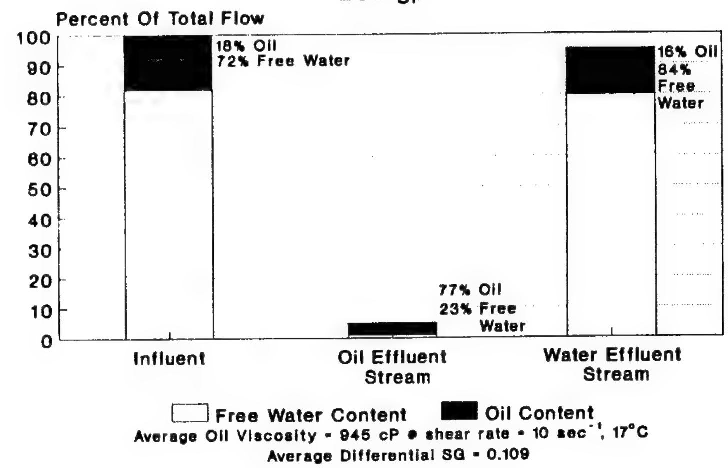


Figure 62c:
Surge Tank Sea Motion Test Series
Test #3: 36% Influent Oil Content
297 gpm

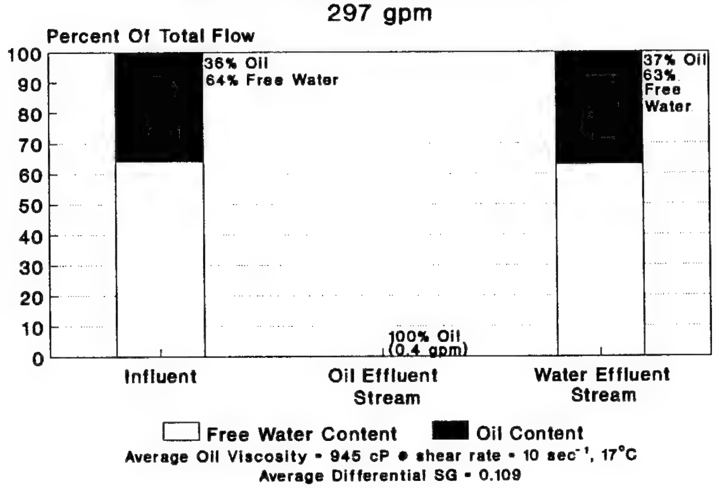


Figure 62d:
Surge Tank Sea Motion Test Series
Test #4: 52% Influent Oil Content
217 gpm

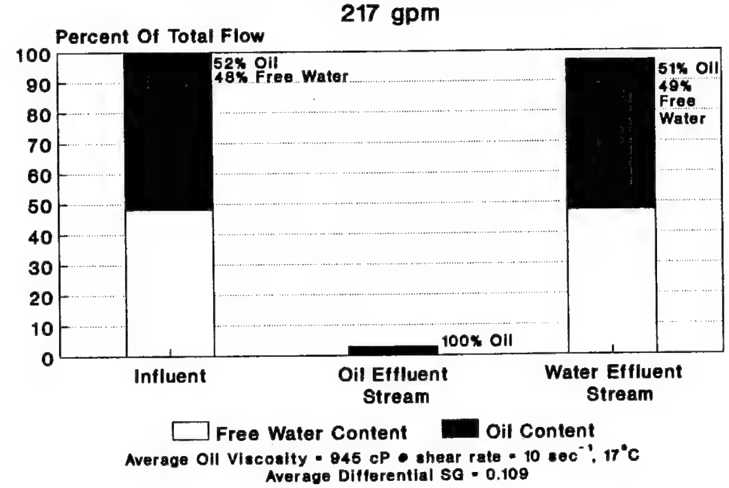
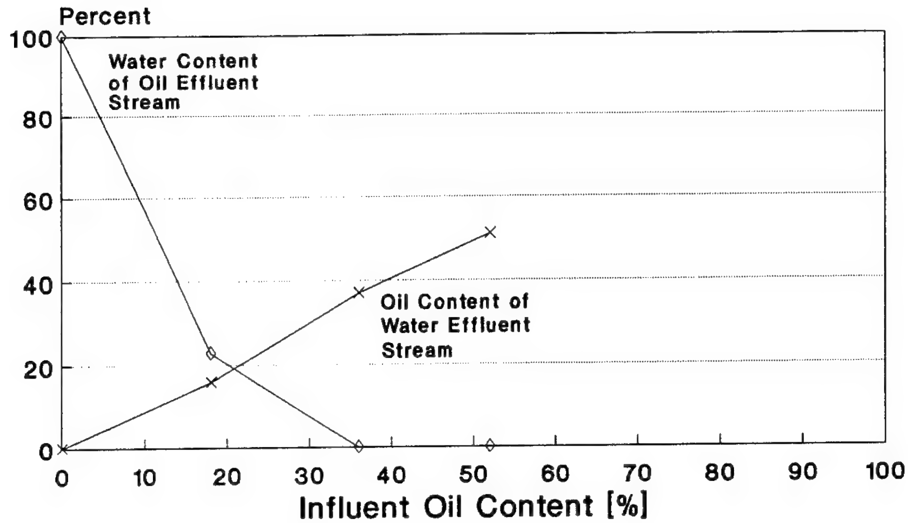


Figure 63:

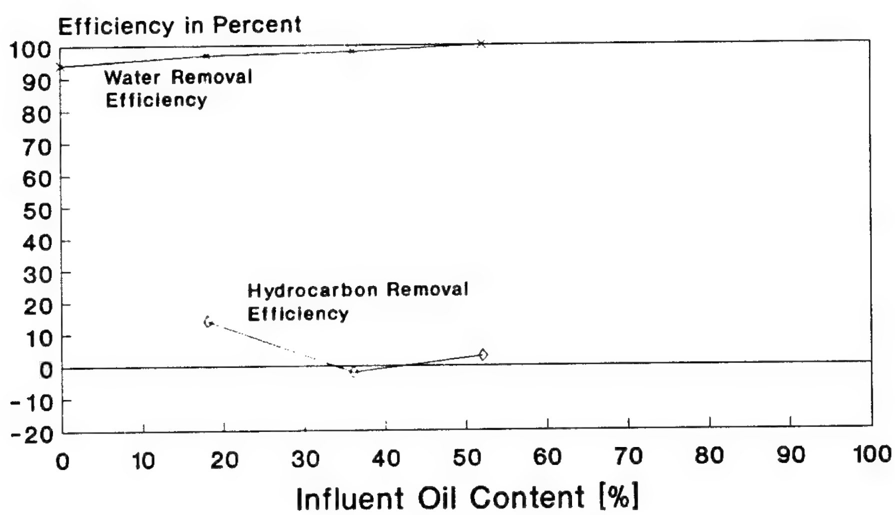
Surge Tank Sea Motion Test Series
Effluent Composition vs. Influent Oil Content



Average Flow Rate = 262gpm
Avg Oil Viscosity = 945 cP @ shear rate = 10 sec^{-1}, 17° C
Average Differential SG = 0.109

Figure 64:

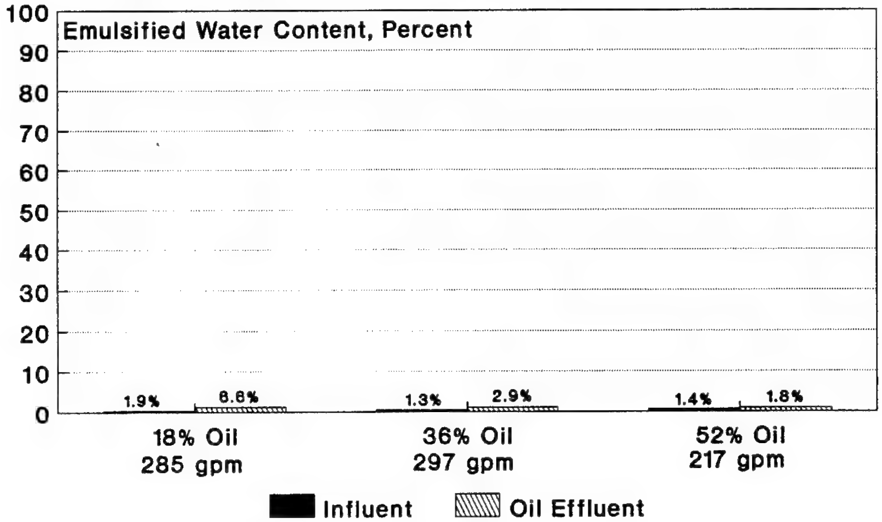
Surge Tank Sea Motion Test Series
Efficiency vs. Influent Oil Content



Average Flow Rate = 262 gpm
Avg Oil Viscosity = 945 cP @ shear rate = 10 sec^{-1}, 17° C
Average Differential SG = 0.109

Figure 65:

Surge Tank Sea Motion Test Series
Emulsified Water Content Before and After Separation



Average Flow Rate = 262 gpm
Avg Oil Viscosity = 945 cP @ shear rate = 10 sec^{-1}, 17 °C
Average Differential SG = 0.109

Figure 66:

Surge Tank Sea Motion Test Series
Influent Line Pressure vs. Time

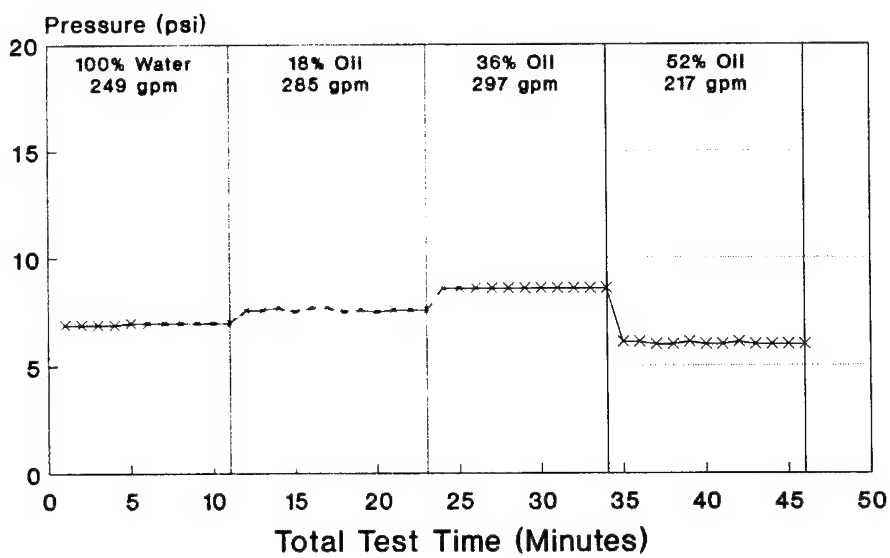


Figure 67:

Impact of Sea Motion on Surge Tank:
Comparison of Oil in Water Effluent vs. Influent Oil Content for Crude Oil and Sea Motion Test Series

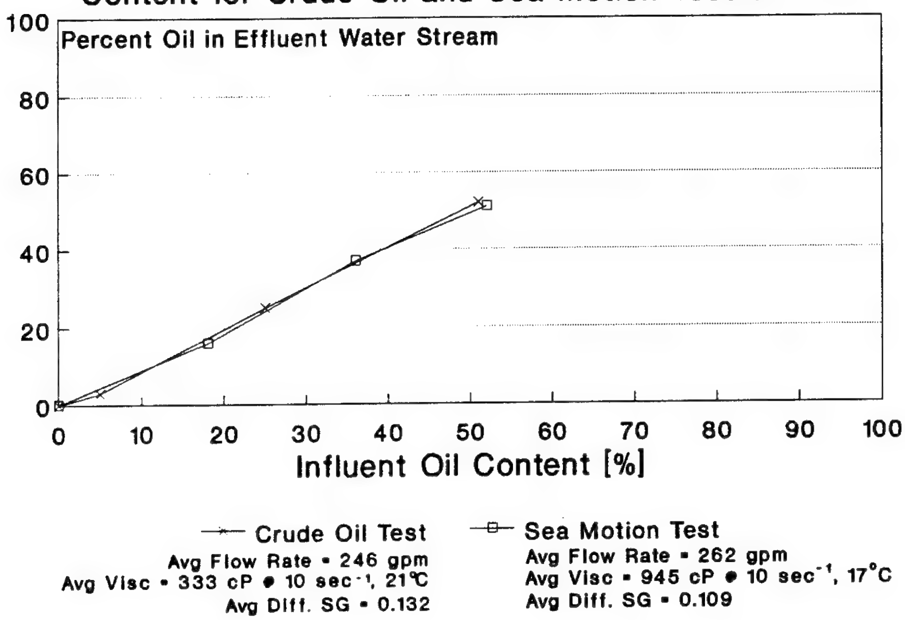


Figure 68:

Impact of Sea Motion on Surge Tank:
Comparison of Water in Oil Effluent vs. Influent Oil Content for Crude Oil and Sea Motion Test Series

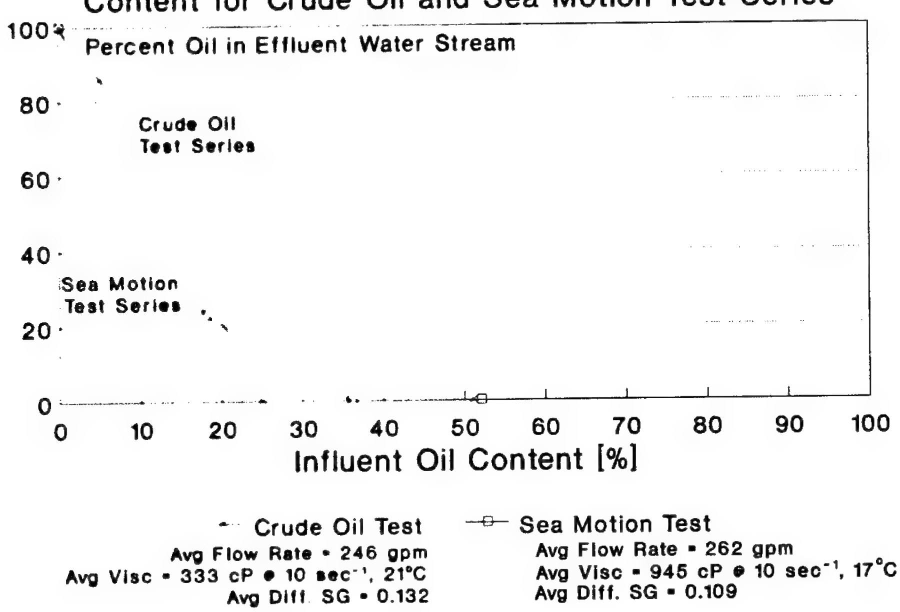


Figure 69:

Impact of Sea Motion on Surge Tank:
Comparison of Water Removal Efficiency vs. Influent Oil Content for Crude Oil and Sea Motion Test Series

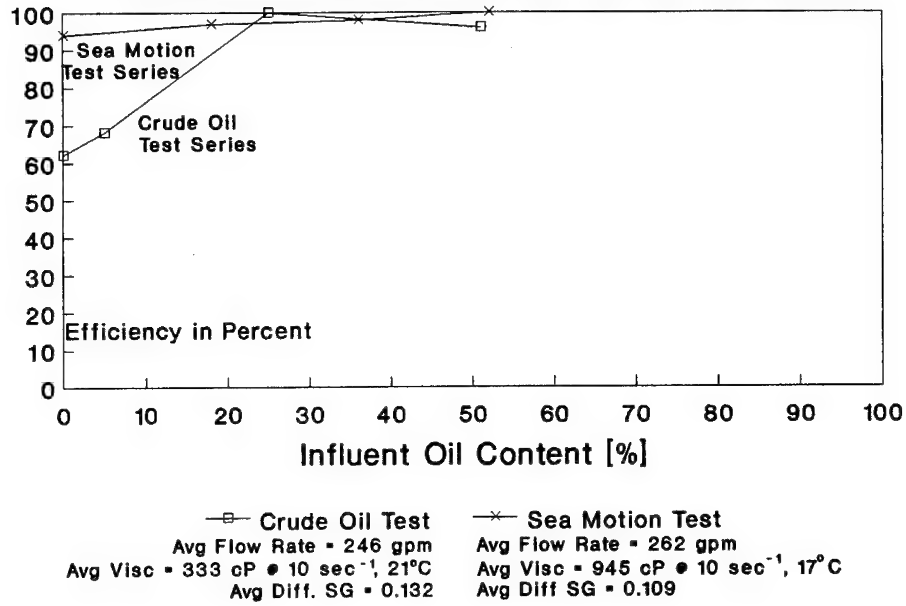


Figure 70:

Impact of Sea Motion on Surge Tank:
Comparison of Hydrocarbon Removal Efficiency vs. Influent Oil Content for Crude Oil and Sea Motion Test Series

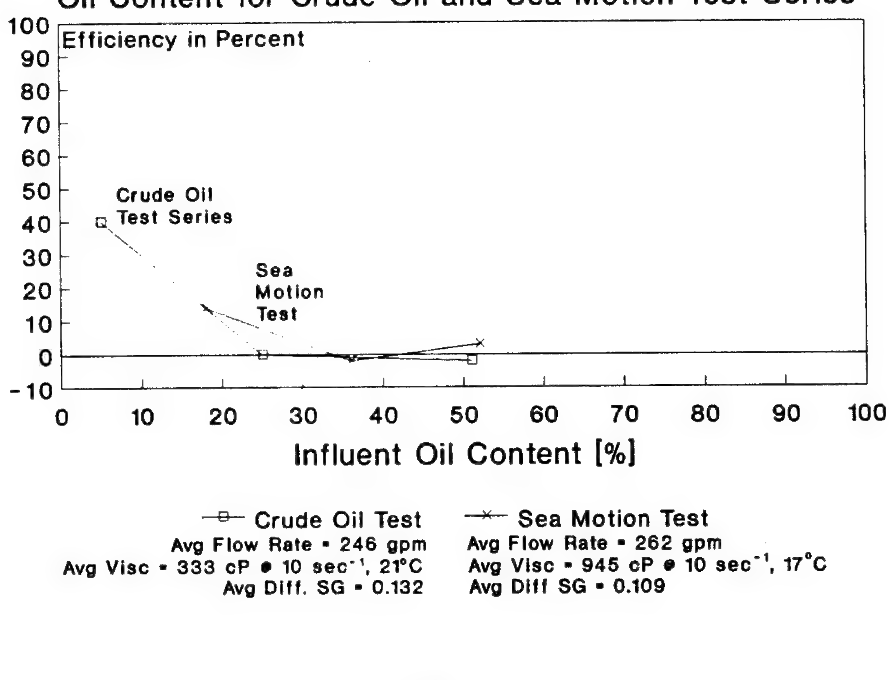


Figure 71: Vortoil Oilspill Separation System

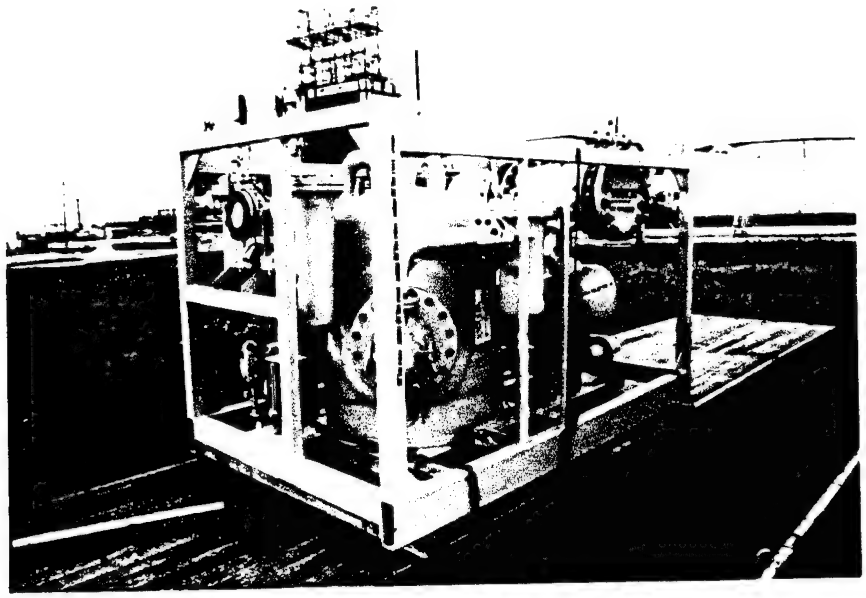


Figure 72: Test Facility Set-Up for Vortoil

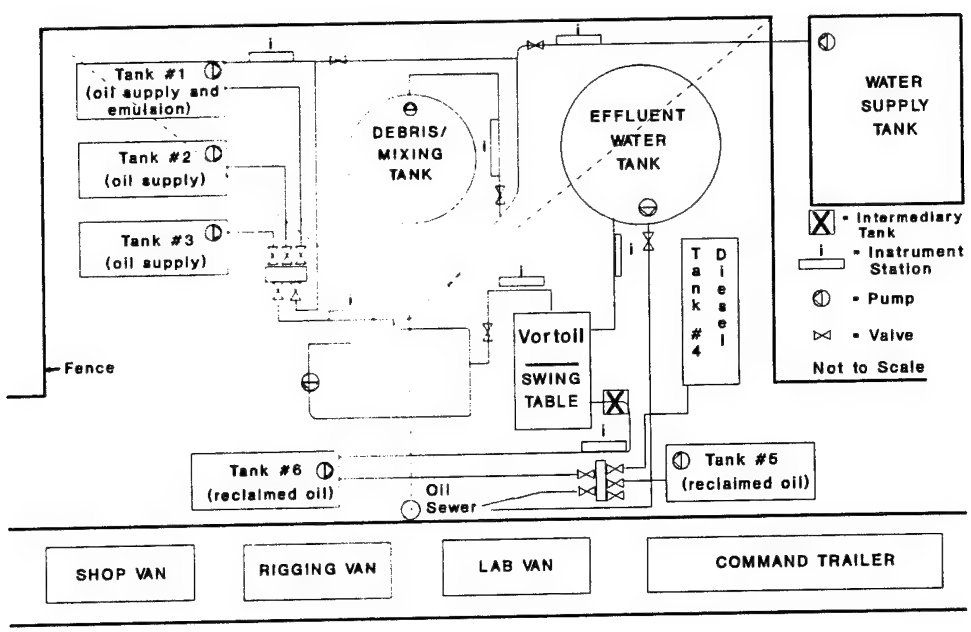


Figure 73: Flow Rate, Temperature and Pressure Plot for Vortoil Crude Oil Test Series, Test #4 (27% Influent Oil Content)

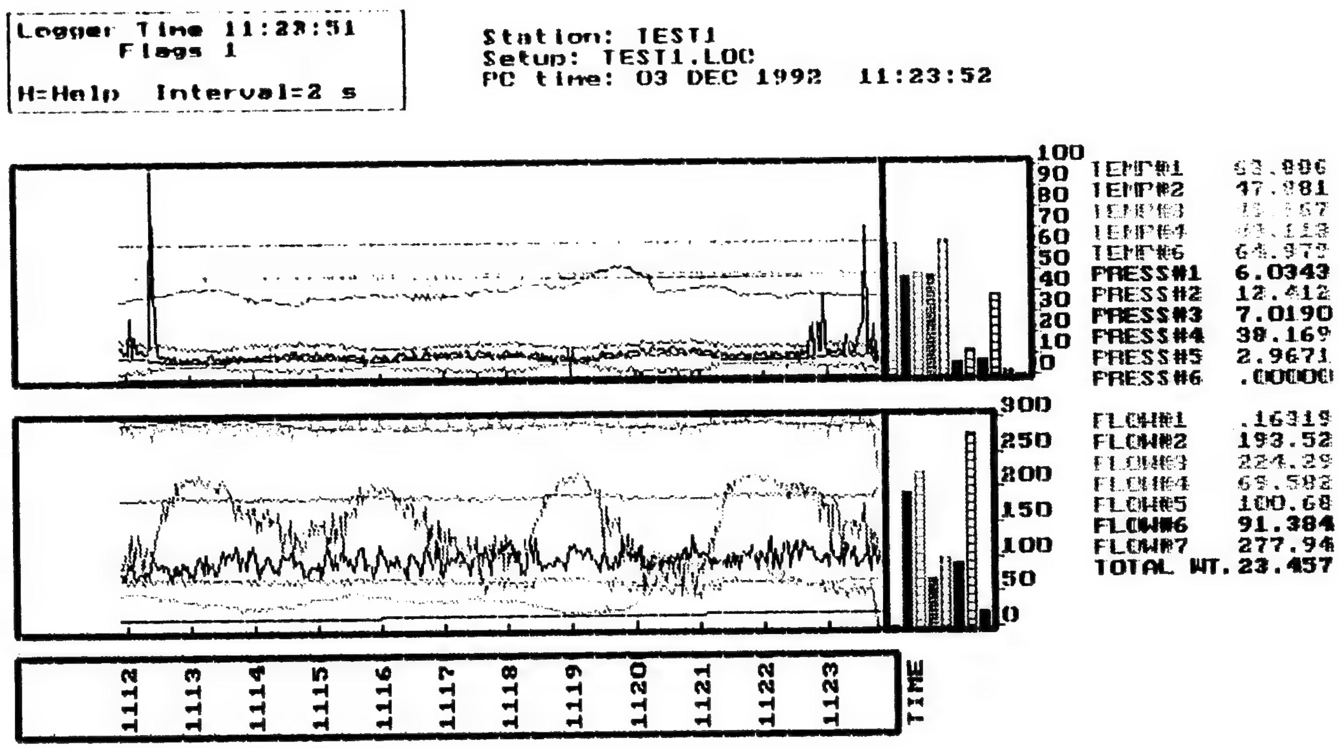


Figure 74a:
Vortoil Crude Oil Test Series
Test# 1: 100% Water Influent
206 gpm

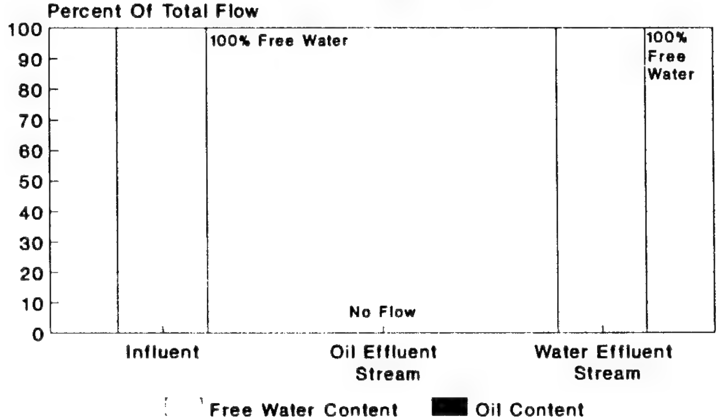


Figure 74b:
Vortoil Crude Oil Test Series
Test# 2: 4% Influent Oil Content
206 gpm

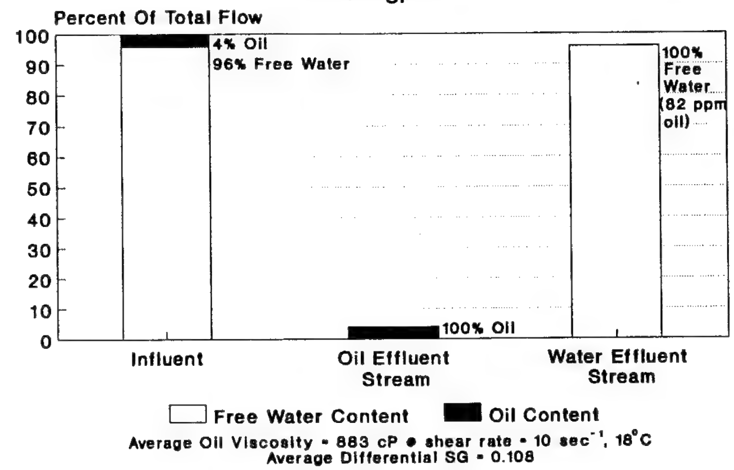


Figure 74c:
Vortoil Crude Oil Test Series
Test #3.1: 53% Capacity (132 gpm), 24% Influent Oil Content, Recirculating Pump at Reduced Capacity

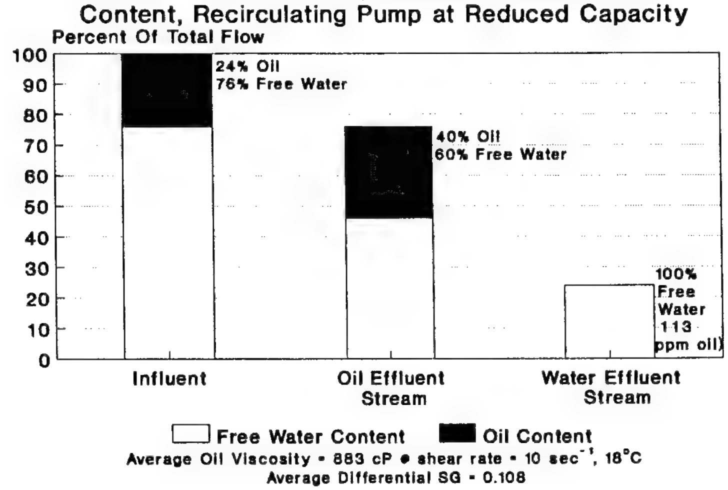


Figure 74d:
Vortoil Crude Oil Test Series
Test #3.2: 49% Capacity (123 gpm), 28% Influent Oil Content, Recirculating Pump at Full Capacity

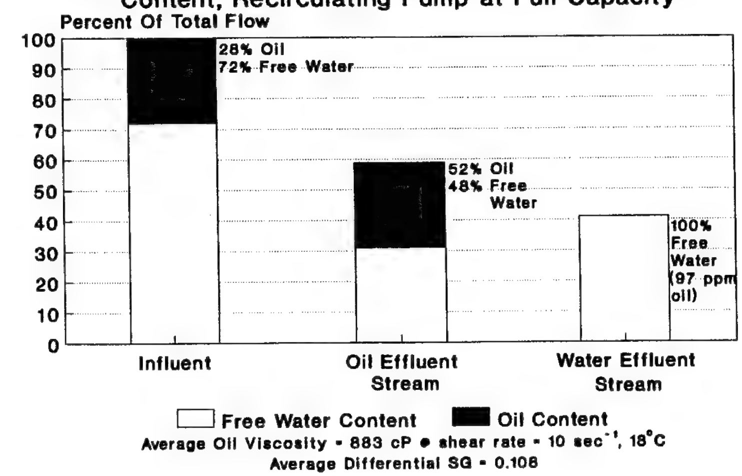
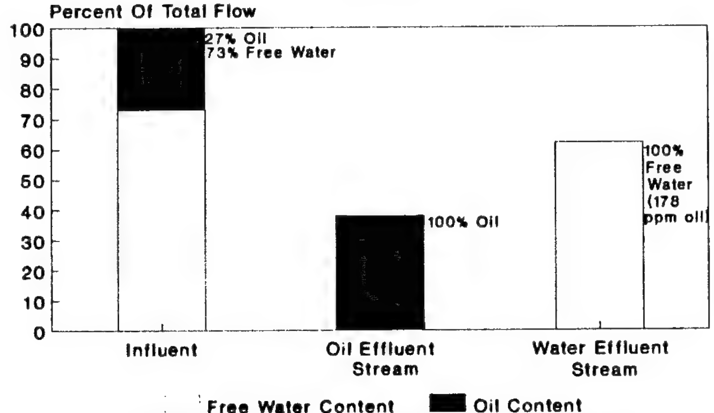
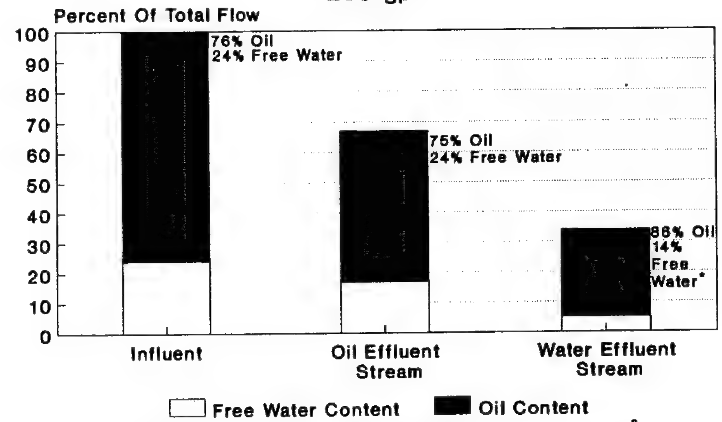


Figure 74e:
Vortoil Crude Oil Test Series
Test #4: 27% Influent Oil Content
261 gpm



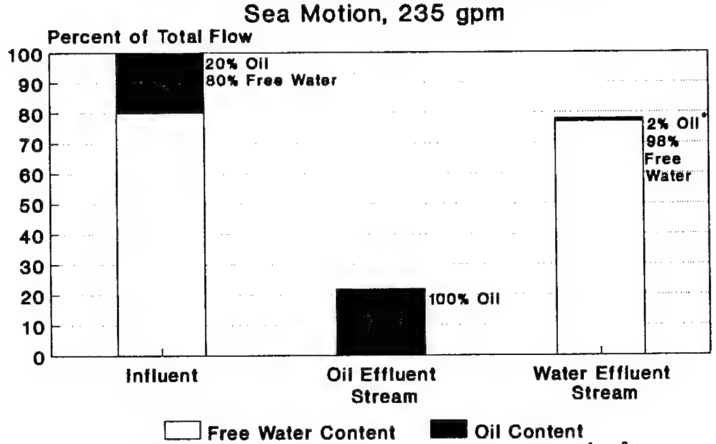
Average Oil Viscosity = 883 cP @ shear rate = 10 sec^{-1}, 18°C
Average Differential SG = 0.108

Figure 74f:
Vortoil Crude Oil Test Series
Test #5: 76% Influent Oil Content
258 gpm



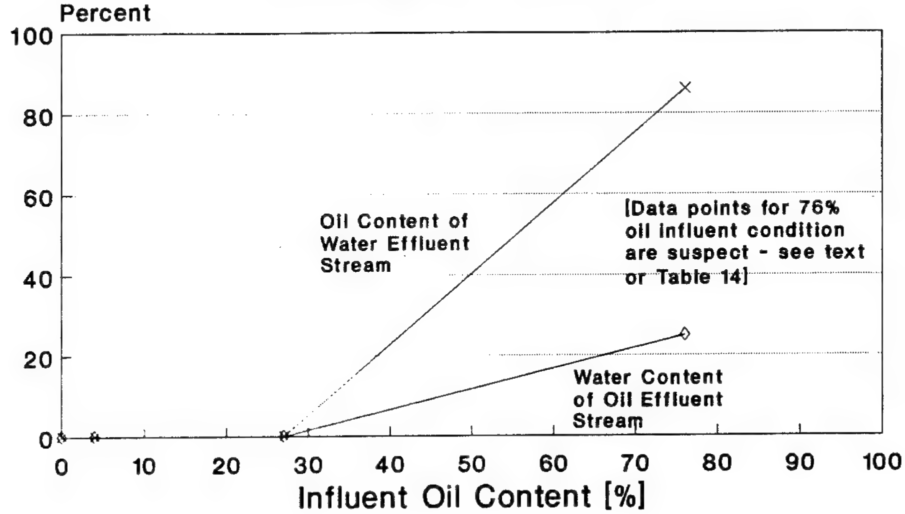
Average Oil Viscosity = 883 cP @ shear rate = 10 sec^{-1}, 18°C
Average Differential SG = 0.108
* See text or Table 14 regarding results from this test.

Figure 74g:
Vortoil Crude Oil Test Series
Test #6: 20% Influent Oil Content With
Sea Motion, 235 gpm



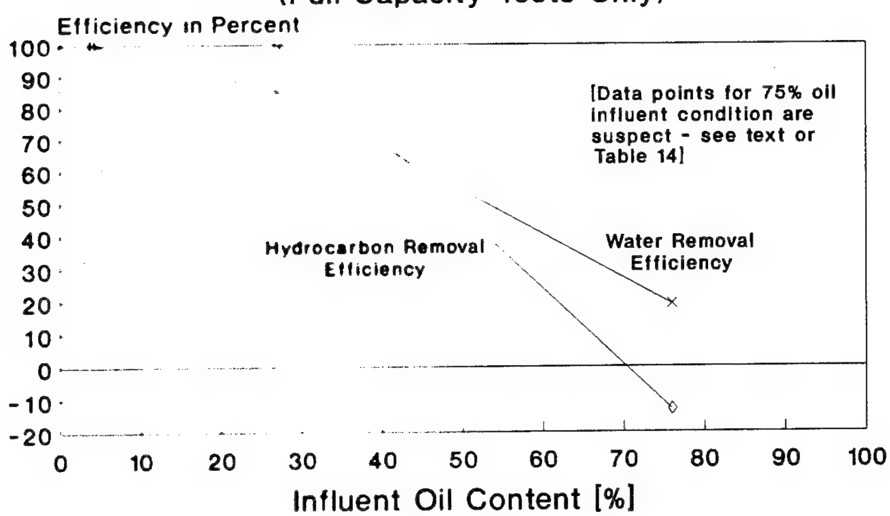
Average Oil Viscosity = 883 cP @ shear rate = 10 sec^{-1}, 18°C
Average Differential SG = 0.108
* See text or Table 14 regarding results from this test.

Figure 75:
Vortoil Crude Oil Test Series
Effluent Composition vs. Influent Oil Content
(Full Capacity Tests Only)



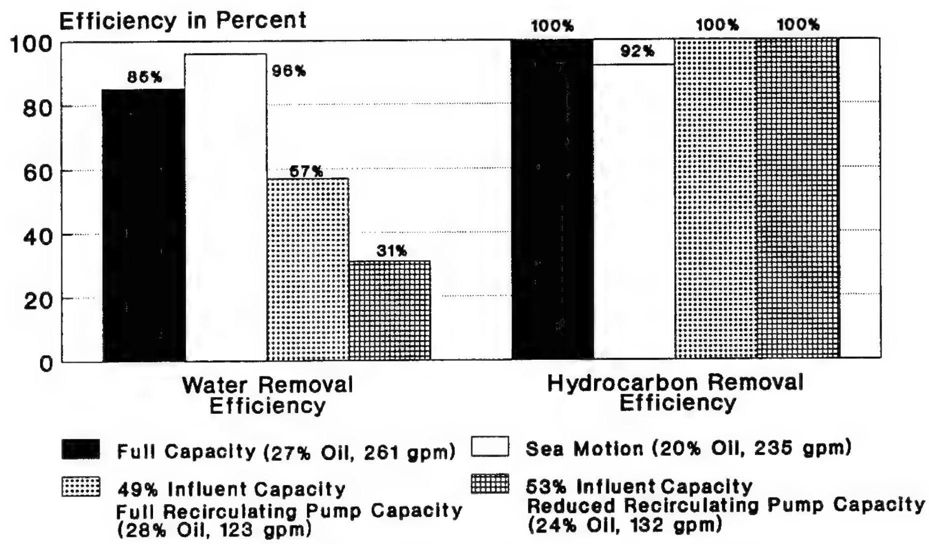
Average Flow Rate = 233 gpm
Average Oil Viscosity = 883 cP @ shear rate = 10 sec^{-1}, 18°C
Average Differential SG = 0.108

Figure 76:
Vortoil Crude Oil Test Series
Efficiency vs. Influent Oil Content
(Full Capacity Tests Only)



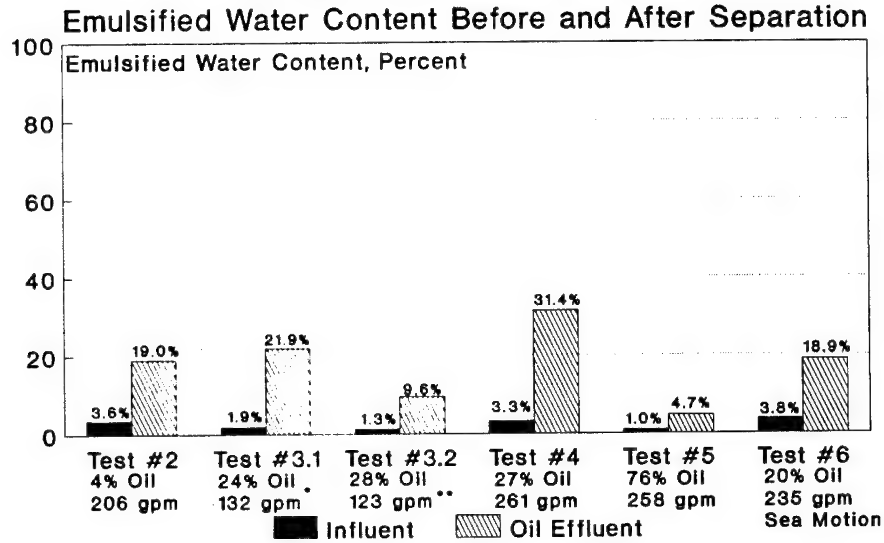
Average Flow Rate = 233 gpm
Average Oil Viscosity = 883 cP @ shear rate = 10 sec^{-1}, 18°C
Average Differential SG = 0.108

Figure 77:
Impact on Vortoil from Reduced Influent Flow Rate and Sea Motion



Average Oil Viscosity = 883 cP @ shear rate = 10 sec^{-1}, 18°C
Average Differential SG = 0.108

Figure 78:
Vortoil Crude Oil Test Series
Emulsified Water Content Before and After Separation

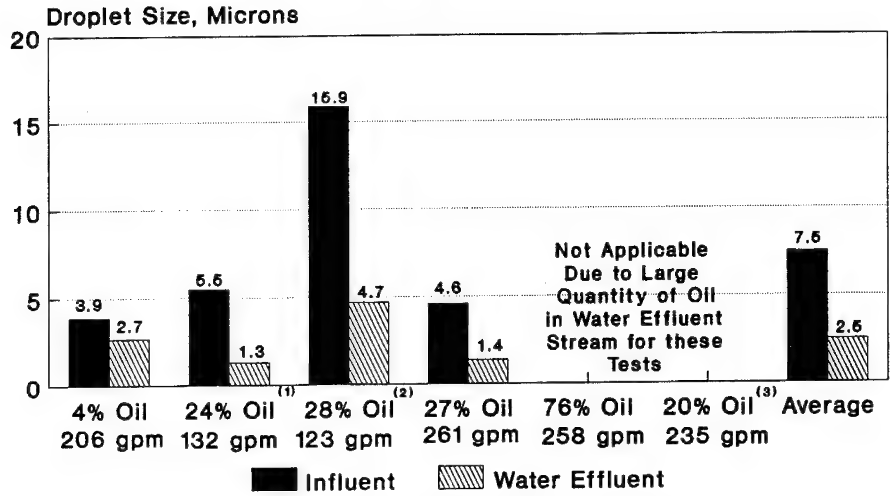


Average Oil Viscosity = 883 cP @ shear rate = 10 sec^{-1}, 18° C
Average Differential SG = 0.108

* Recirculating Pump at Reduced Capacity ** Recirculating Pump at Full Capacity

Figure 79:

Vortoil Crude Oil Test Series
Change in Mean Oil Droplet Size
After Separation



(1) Recirculating Pump at Reduced Capacity (3) Sea Motion Test
(2) Recirculating Pump at Full Capacity

Average Oil Viscosity = 883 cP @ shear rate = 10 sec^{-1}, 18°C
Average Differential SG = 0.108

Figure 80:

Vortoil Crude Oil Test Series
Influent and Water Effluent Line Pressure vs. Time

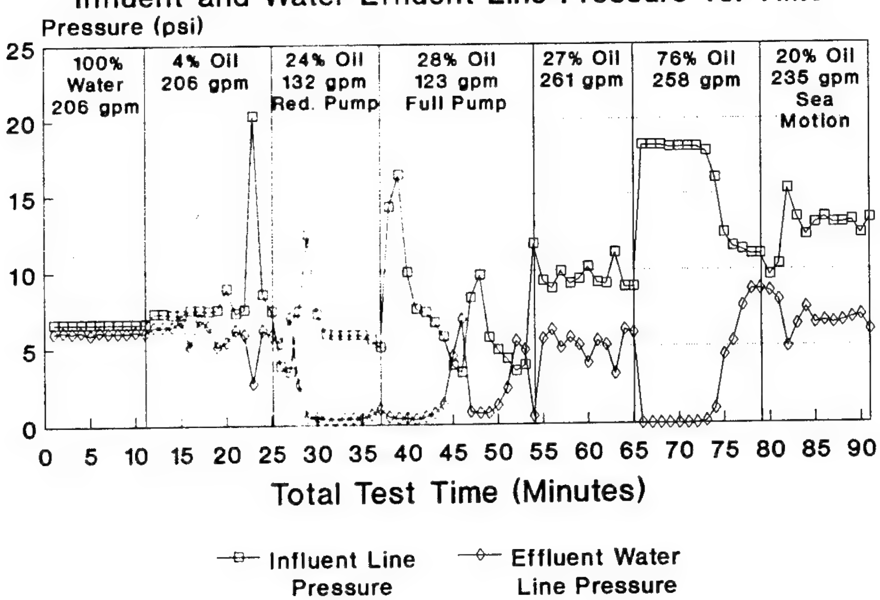


Figure 81a:
Vortoil Mousse Test Series
Test #1: 100% Water Influent
215 gpm

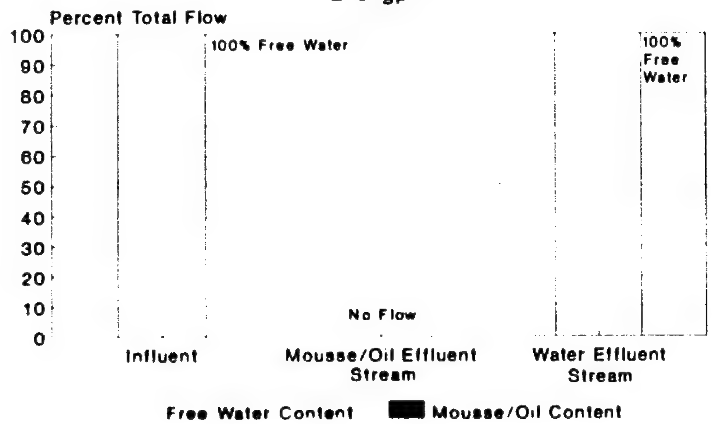


Figure 81b:
Vortoil Mousse Test Series
Test #2: 15% Influent Mousse Content
217 gpm

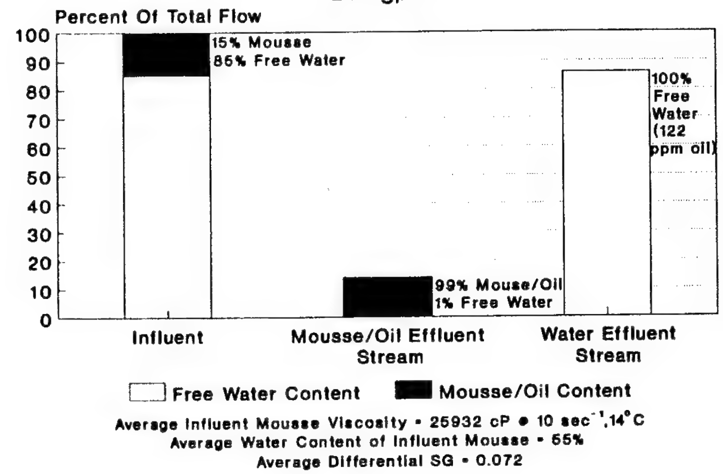


Figure 81c:
Vortoil Mousse Test Series
Test #3: 27% Mousse Influent Content
212 gpm

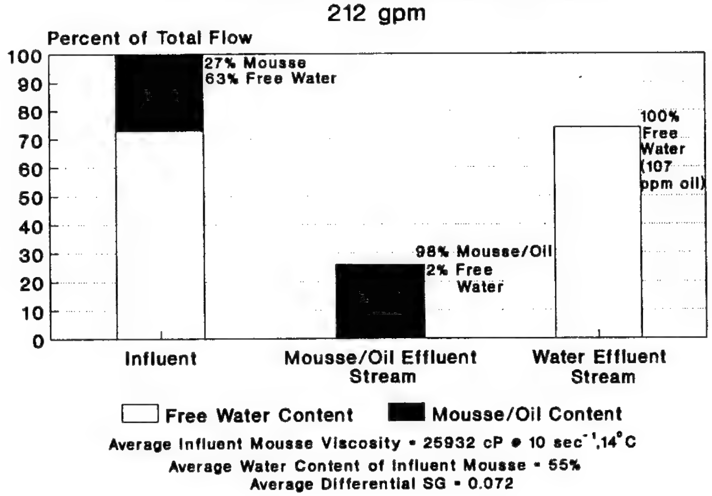


Figure 81d:
Vortoil Mousse Test Series
Test #4: 61% Mousse Influent Content
266 gpm

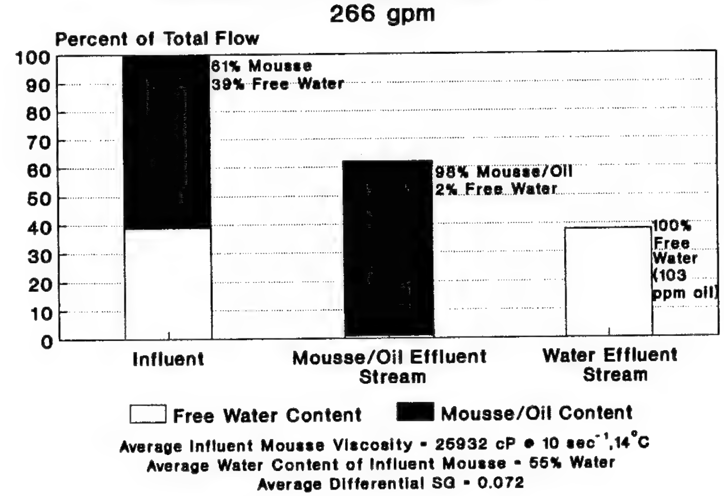


Figure 81e:

Vortoil Mousse Test Series
Test #5: 100% Mousse Influent
191 gpm

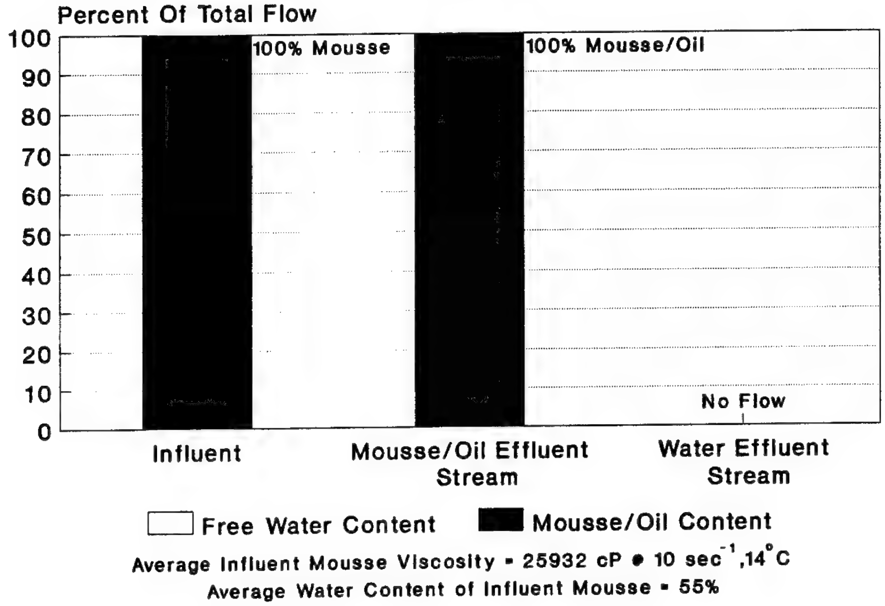


Figure 82:

Vortoil Mousse Test Series
Effluent Composition vs. Influent Oil Content

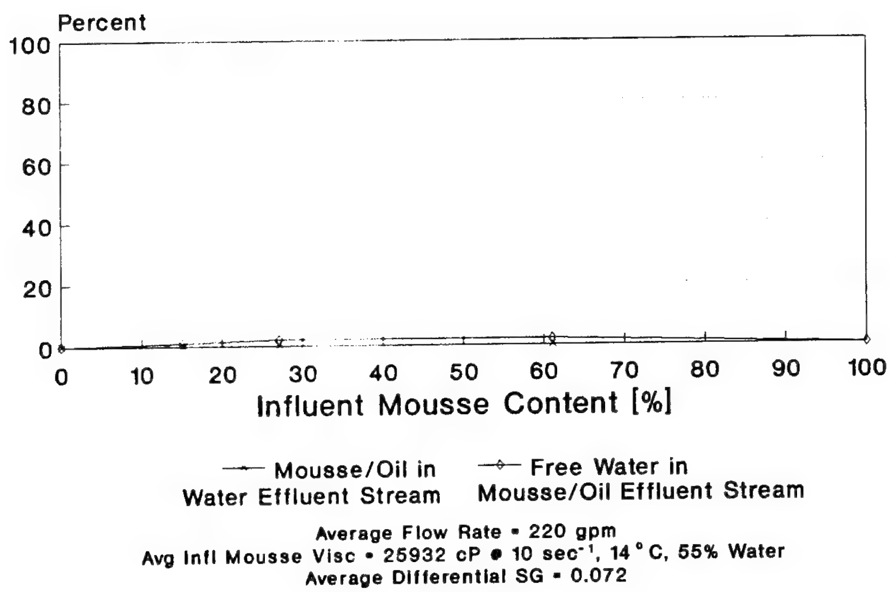
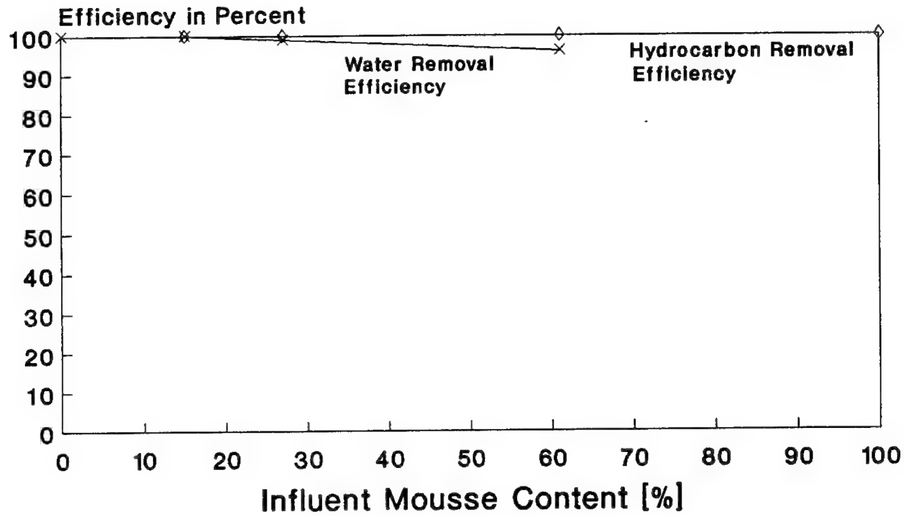
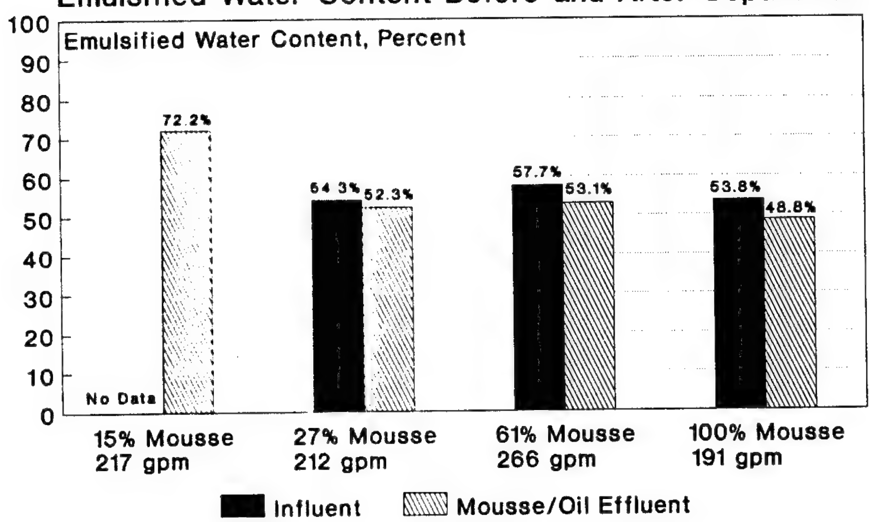


Figure 83:
Vortoil Mousse Test Series
Efficiency vs. Influent Mousse Content



Average Flow Rate = 220 gpm
Avg Infl Mousse Visc = 25932 cP @ 10 sec^{-1}, 14° C, 55% Water
Average Differential SG = 0.072

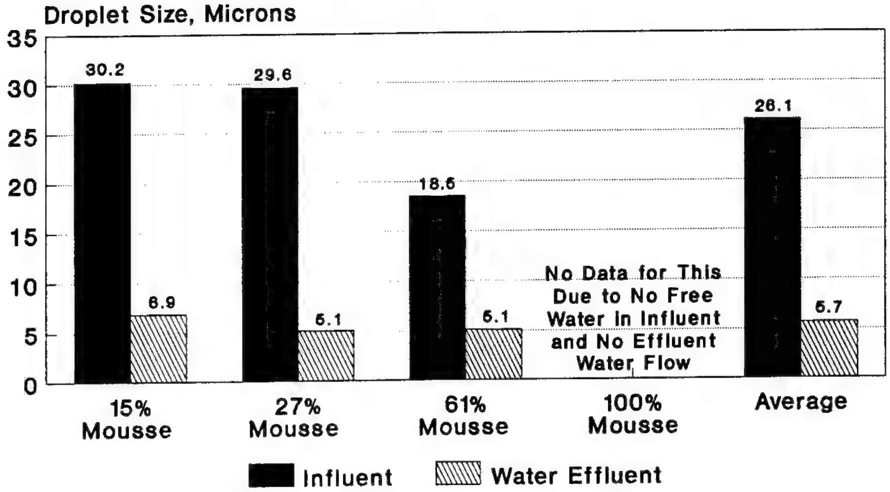
Figure 84:
Vortoil Mousse Test Series
Emulsified Water Content Before and After Separation



Average Flow Rate = 220 gpm
Avg Infl Mousse Visc = 25932 cP @ 10 sec , 14 C, 55% Water
Average Differential SG = 0.072

Figure 85:

Vortoil Mousse Test Series
Change in Mean Oil Droplet Size
After Separation



Average Flow Rate = 220 gpm
Avg Infl Mousse Visc = 25932 cP @ 10 sec^{-1}, 14 °C, 55% Water
Average Differential SG = 0.072

Figure 86:

Vortoil Mousse Test Series
Influent and Water Effluent Line Pressure vs. Time

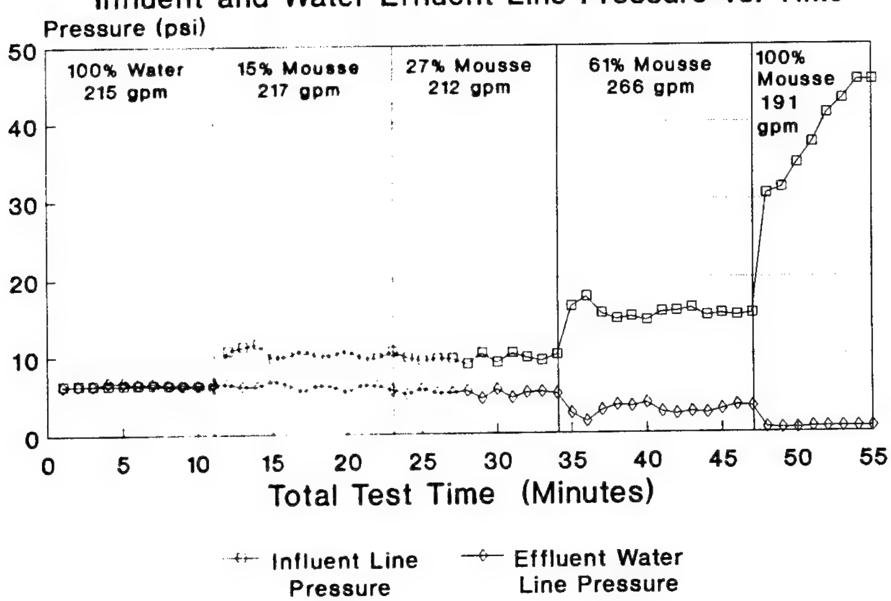
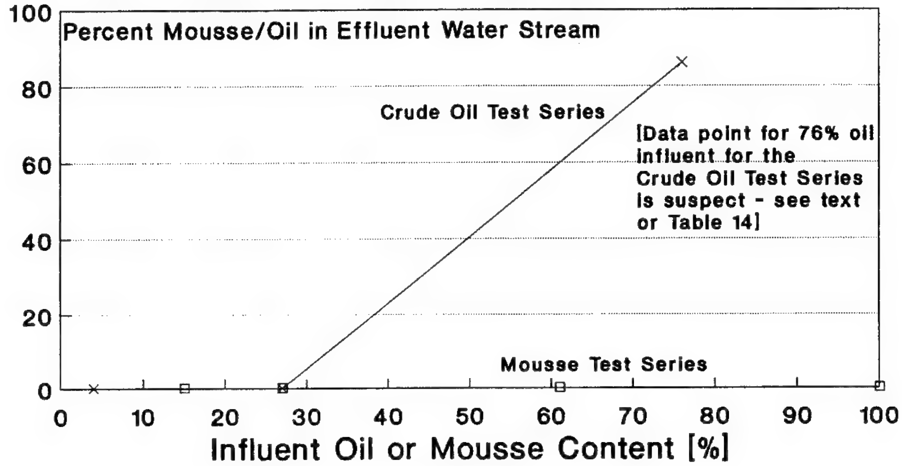


Figure 87:

Impact of Mousse on Vortoil: Comparison of Water Effluent Oil Content vs. Influent Mousse/ Oil Content for Crude Oil and Mousse Test Series

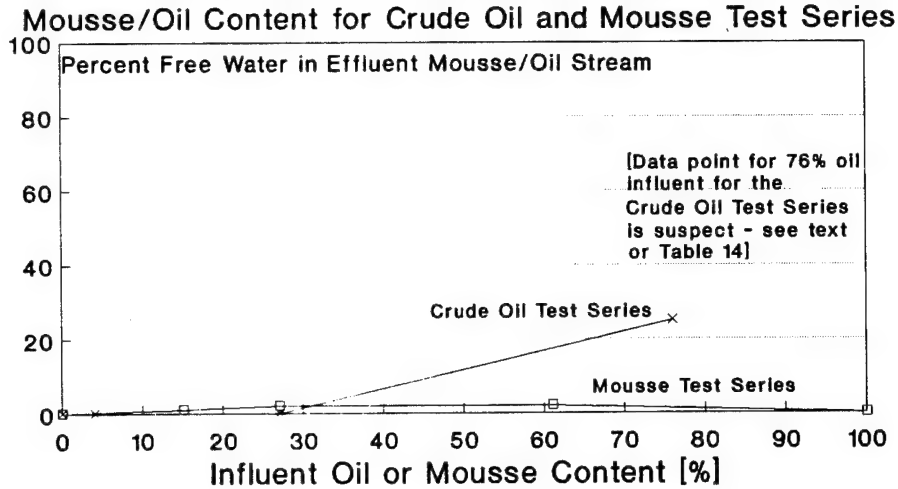


Crude Oil Test
Avg Flow Rate - 233 gpm
Avg Visc - 883 cP @ 10 sec^{-1}, 18°C
Avg Diff. SG - 0.108

Mousse Test
Avg Flow Rate - 220 gpm
Avg Visc - 25932 cP @ 10 sec^{-1}, 14°C
Avg Diff. SG - 0.072

Figure 88:

Impact of Mousse on Vortoil: Comparison of Free Water Content in Mousse/Oil Effluent vs. Influent Mousse/Oil Content for Crude Oil and Mousse Test Series



Crude Oil Test
Avg Flow Rate - 233 gpm
Avg Visc - 883 cP @ 10 sec^{-1}, 18°C
Avg Diff. SG - 0.108

Mousse Test
Avg Flow Rate - 220 gpm
Avg Visc - 25932 cP @ 10 sec^{-1}, 14°C
Avg Diff. SG - 0.072

Figure 89:
Impact of Mousse on Vortoil: Comparison of Water Removal Efficiency vs. Influent Mousse/ Oil Content for Crude Oil and Mousse Test Series

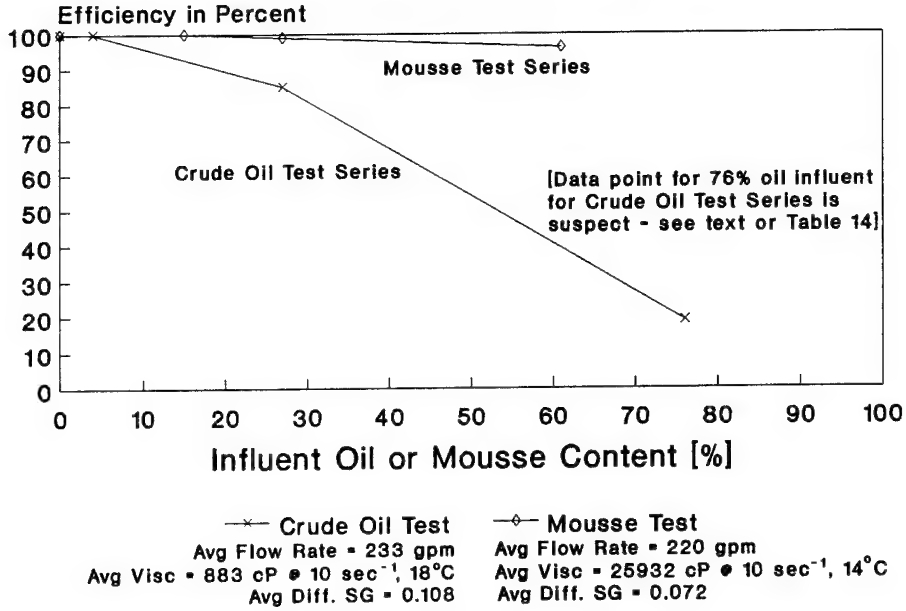


Figure 90:
Impact of Mousse on Vortoil: Comparison of Hydrocarbon Removal Efficiency vs. Influent Mousse/ Oil Content for Crude Oil and Mousse Test Series

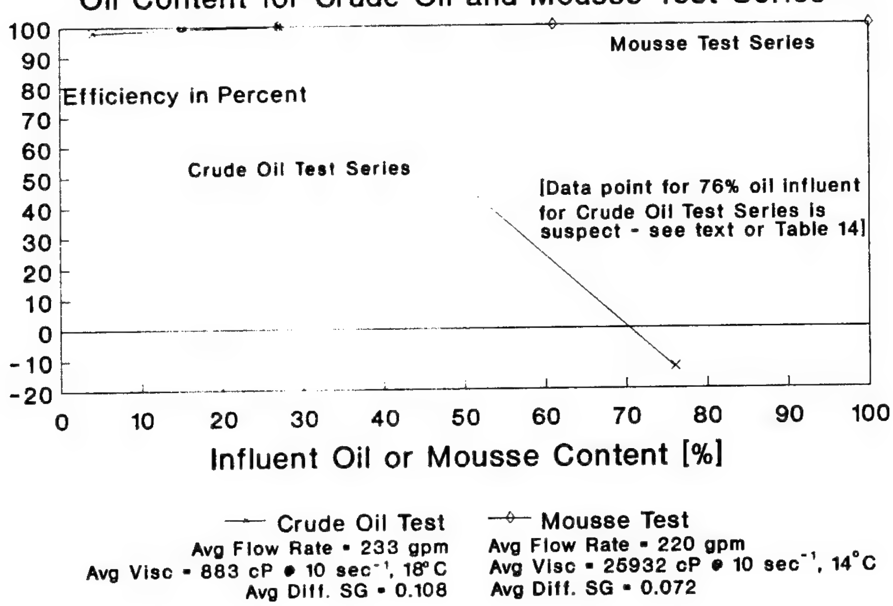


Figure 91a:
Vortoil Mousse With Emulsion Breaker Test Series
Test #1: 100% Water Influent
208 gpm

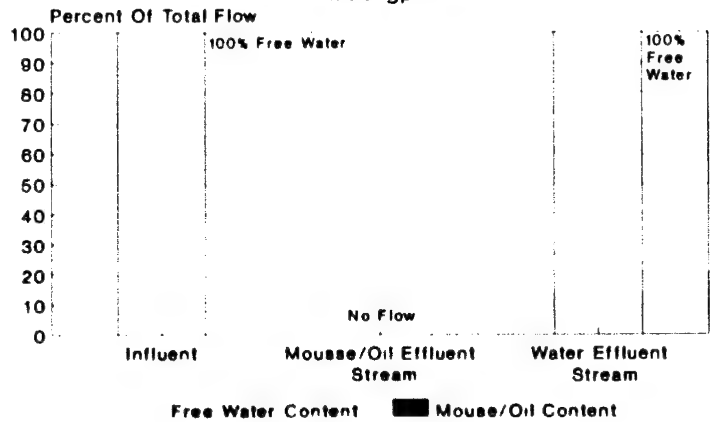


Figure 91b:
Vortoil Mousse With Emulsion Breaker Test Series
Test #2: 25% Influent Mousse Content
263 gpm

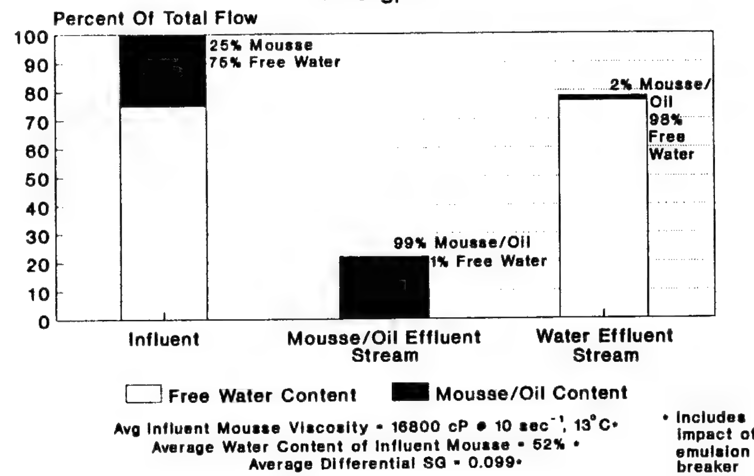


Figure 91c:
Vortoil Mousse With Emulsion Breaker Test Series
Test #3: 26% Influent Mousse Content
280 gpm

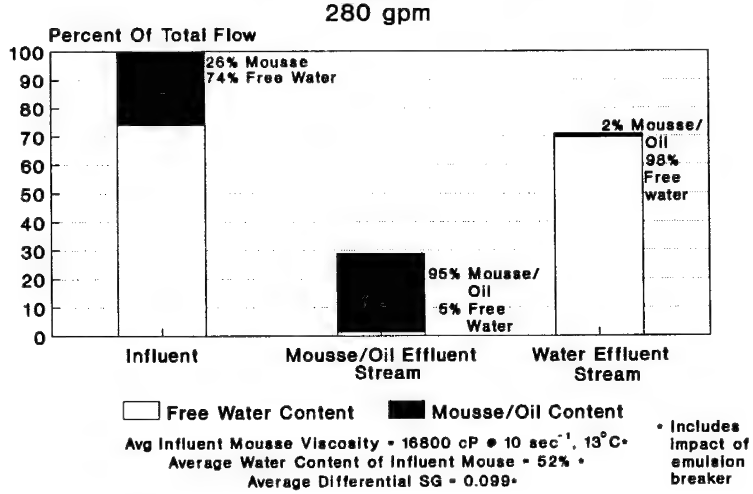


Figure 91d:
Vortoil Mousse With Emulsion Breaker Test Series
Test #4: 52% Influent Mousse Content
274 gpm

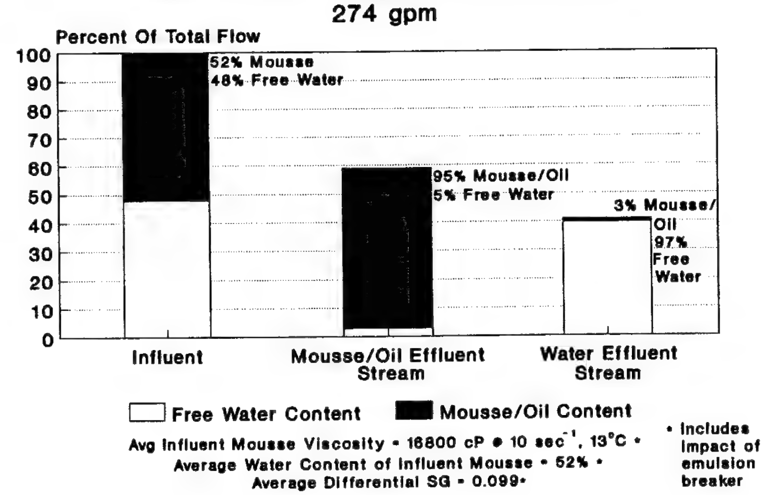
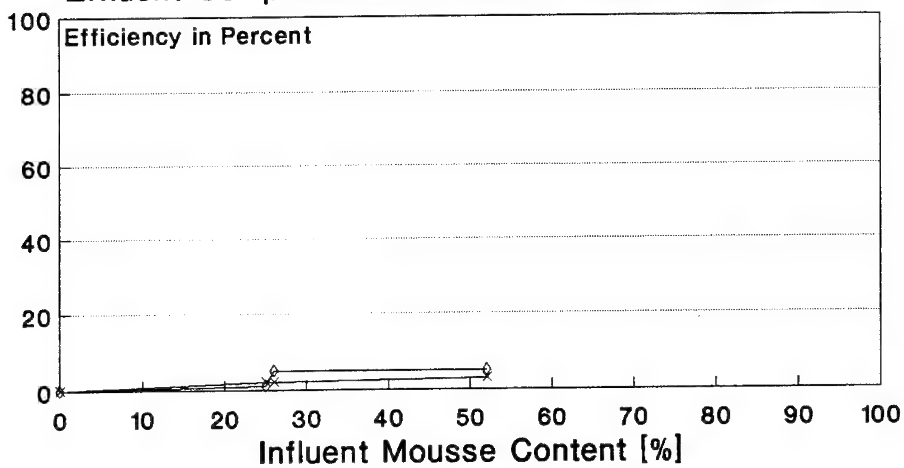


Figure 92:

Vortoil Mousse With Emulsion Breaker Test Series
Effluent Composition vs. Influent Mousse Content

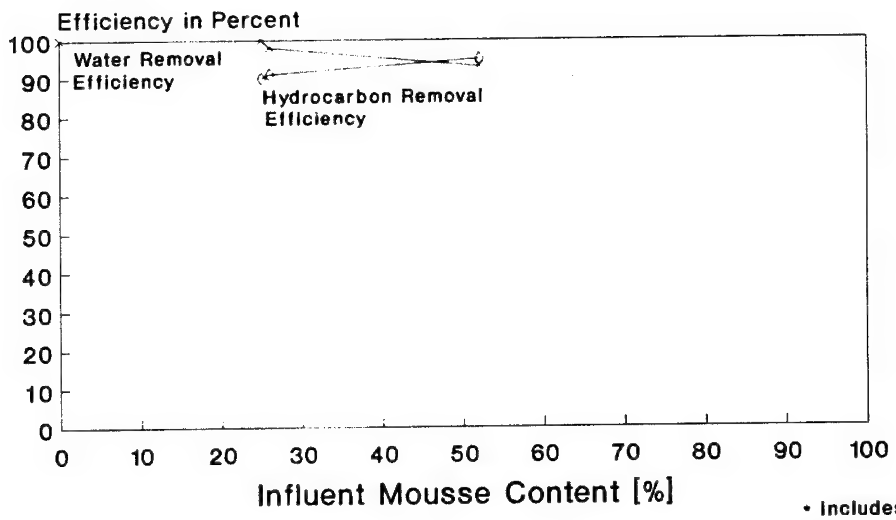


Average Flow Rate = 256 gpm
Avg Infl Mousse Visc = 16800 cP @ 10 sec^{-1}, 13°C, 52% Water*
Average Differential SG = 0.099*

* Includes impact of emulsion breaker

Figure 93:

Vortoil Mousse With Emulsion Breaker Test Series
Efficiency vs. Influent Mousse Content



Average Flow Rate = 220 gpm
Avg Infl Mousse Visc = 16800 cP @ 10 sec^{-1}, 13°C, 52% Water*
Average Differential SG = 0.099*

* Includes impact of emulsion breaker

Figure 94:

Vortoil Mousse With Emulsion Breaker Test Series
Emulsified Water Content Before and After Separation

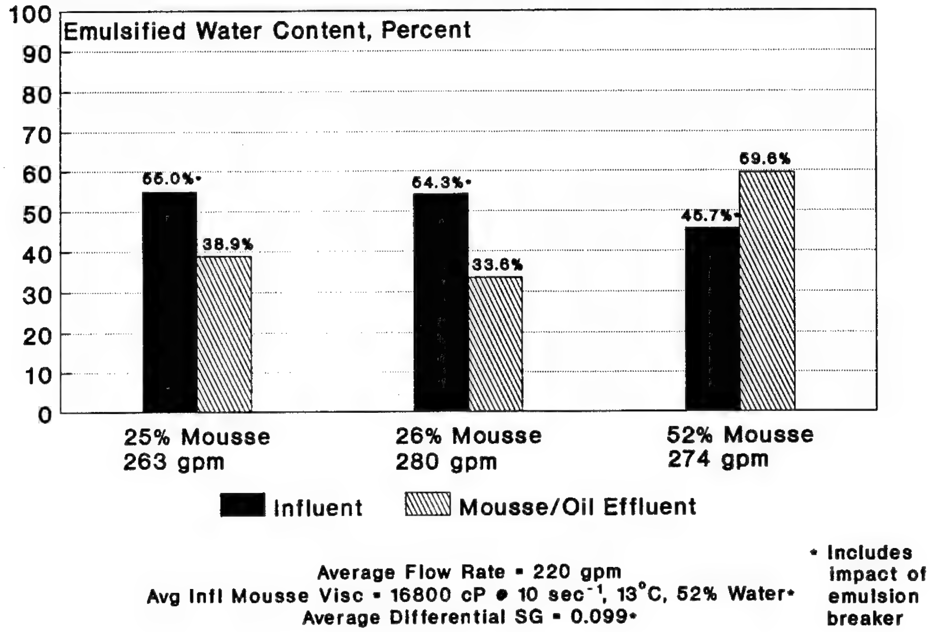


Figure 95:

Vortoil Mousse With Emulsion Breaker Test Series:
Impact of Emulsion Breaker on Viscosity

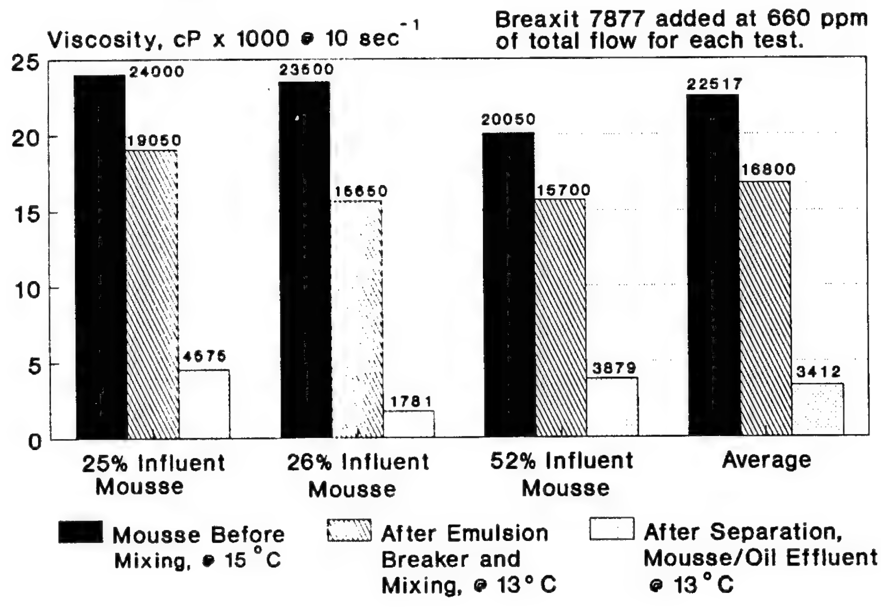


Figure 96:

Vortoil Mousse With Emulsion Breaker Test Series Influent and Effluent Water Line Pressure vs. Time

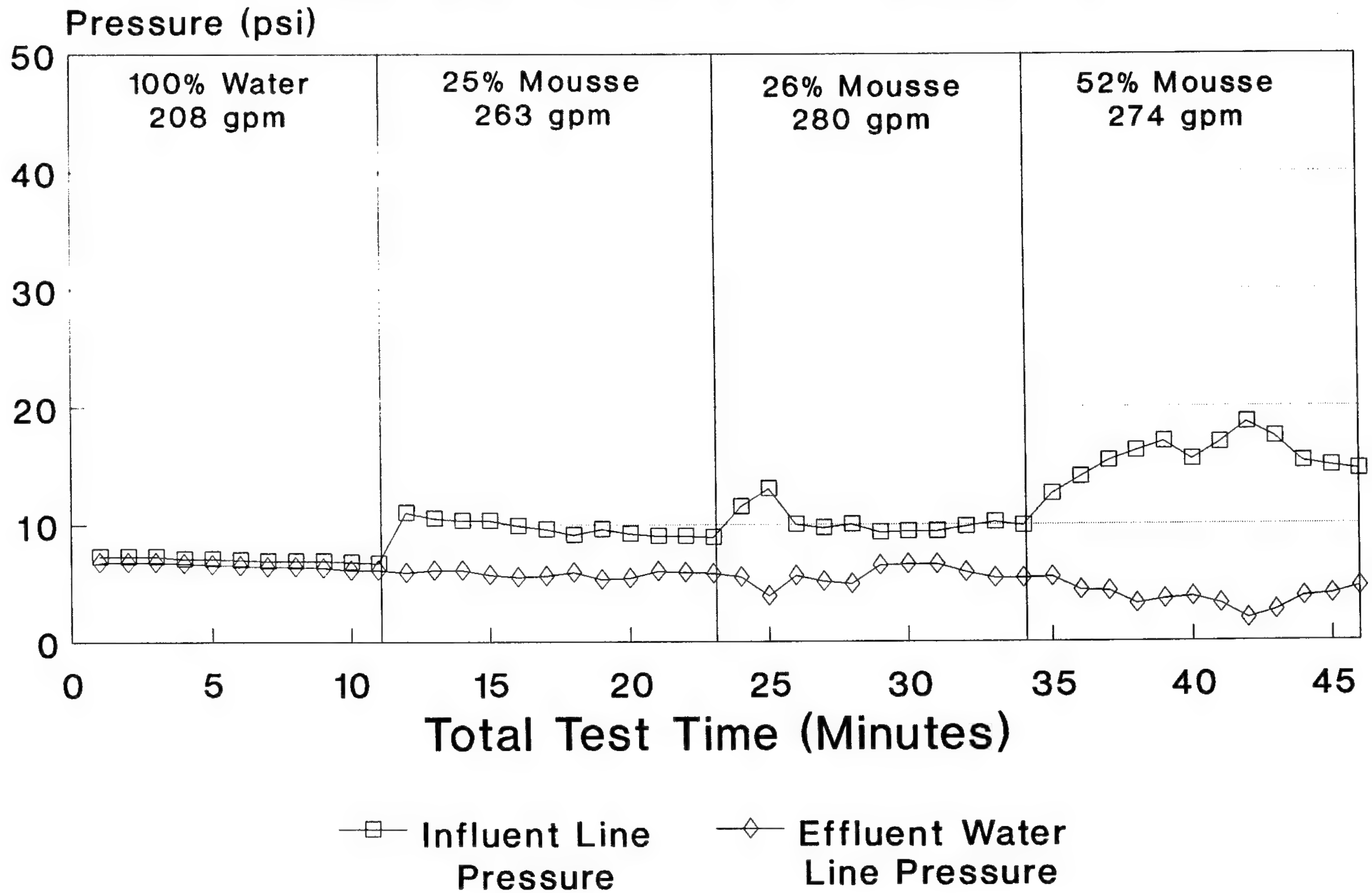


Figure 97:

Impact of Emulsion Breaker on Vortoil:
Comparison of Mousse/Oil Content in Water Effluent for Mousse and Mousse With Emulsion Breaker Test Series

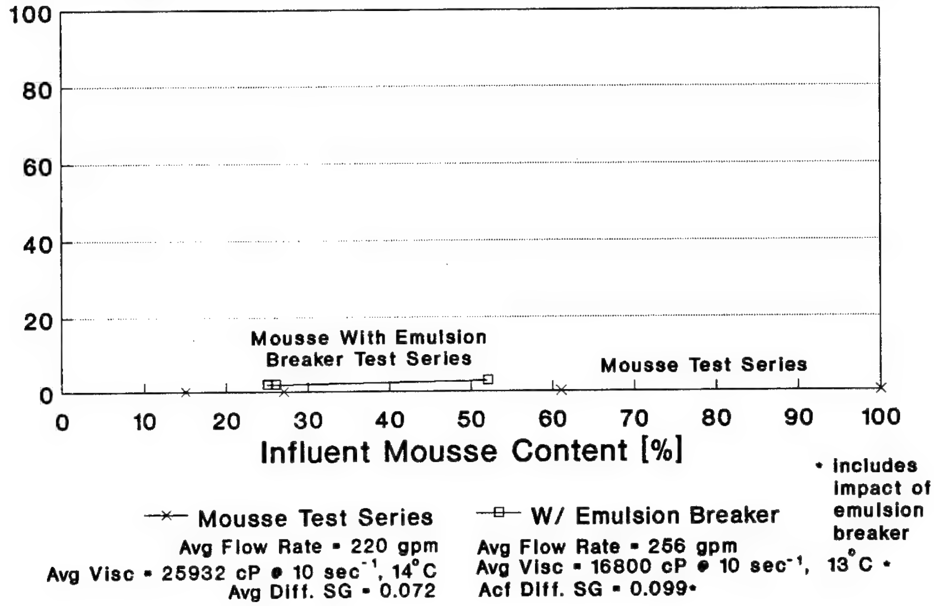


Figure 98:

Impact of Emulsion Breaker on Vortoil:
Comparison of Free Water in Mousse/Oil Effluent for Mousse and Mousse with Emulsion Breaker Test Series

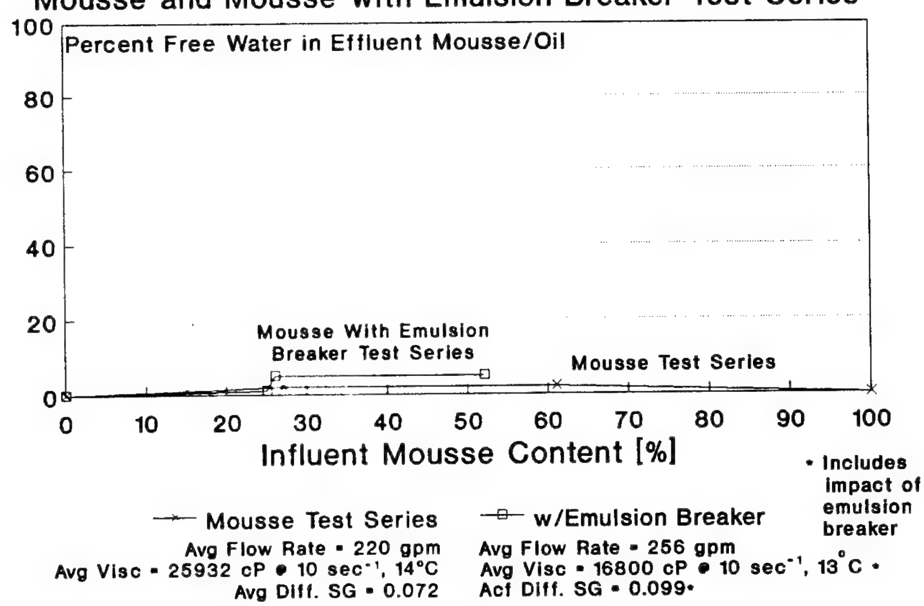


Figure 99:

Impact of Emulsion Breaker on Vortoil: Comparison of Water Removal Efficiency vs. Influent Mousse Content for Mousse and Mousse With Emulsion Breaker Test Series

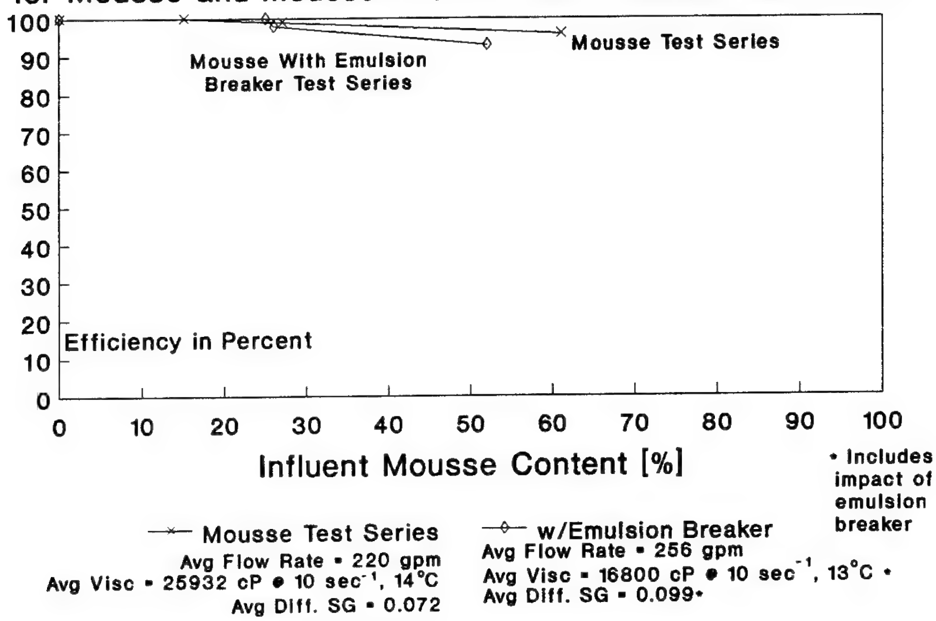


Figure 100:

Impact of Emulsion Breaker on Vortoil: Comparison of Hydrocarbon Removal Efficiency vs. Influent Mousse Content for Mousse and Mousse With Emulsion Breaker Test Series

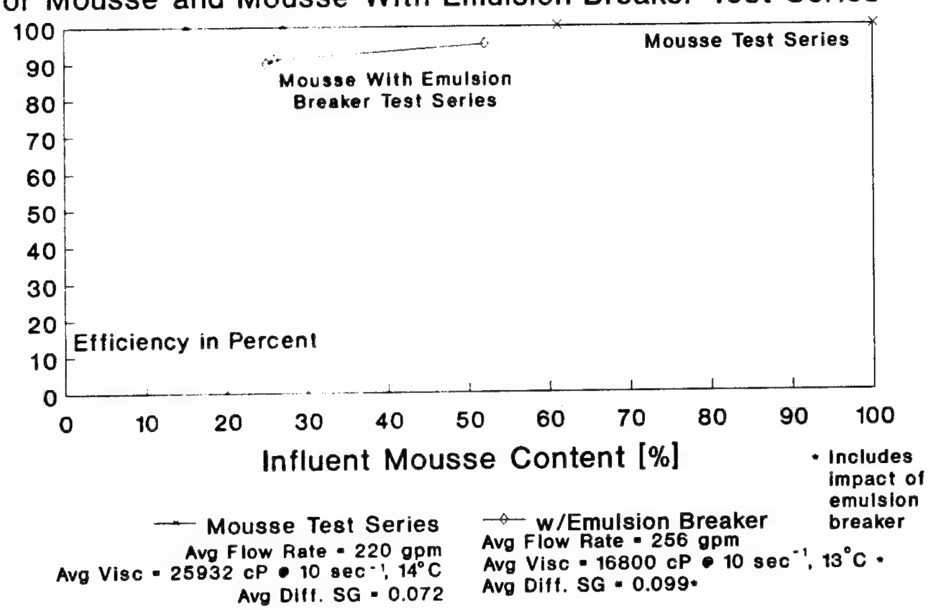
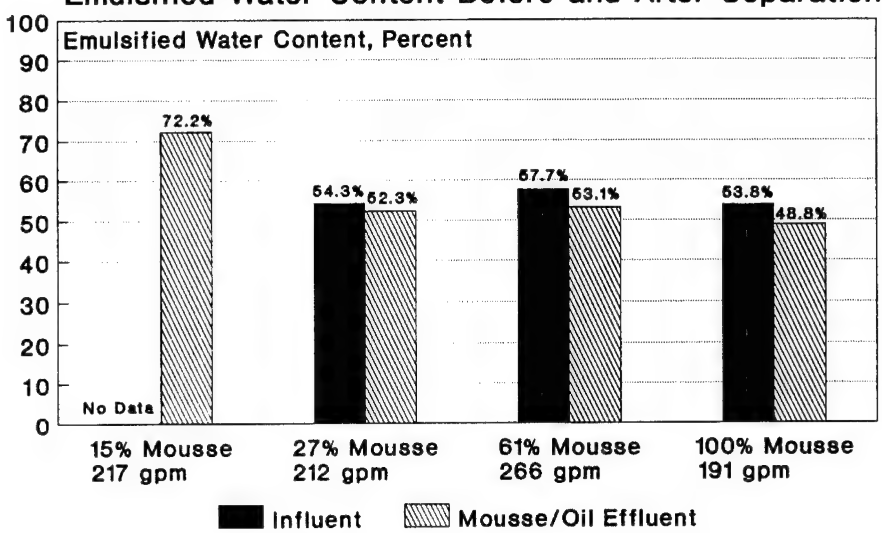
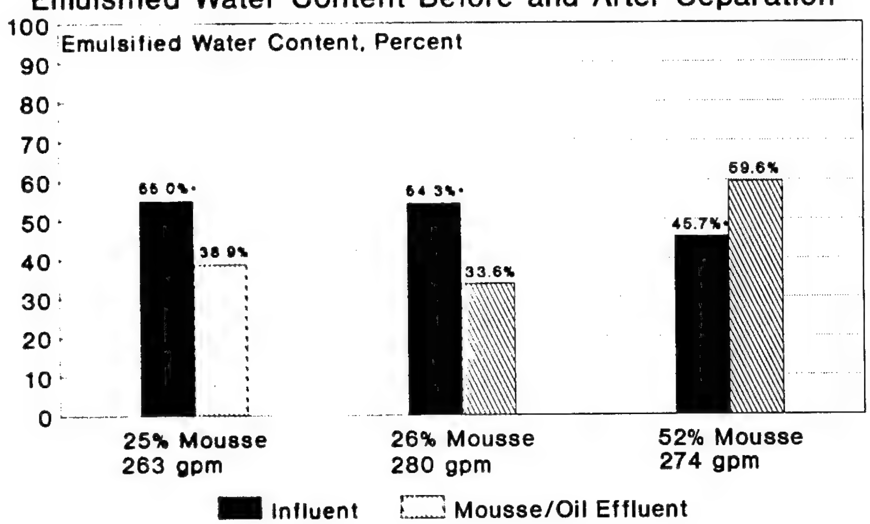


Figure 101:
Vortoil Mousse Test Series
Emulsified Water Content Before and After Separation



Average Flow Rate = 220 gpm
Avg Infl Mousse Visc = 25932 cP @ 10 sec , 14 C, 55% Water
Average Differential SG = 0.072

Figure 102:
Vortoil Mousse With Emulsion Breaker Test Series
Emulsified Water Content Before and After Separation



Average Flow Rate = 220 gpm
Avg Infl Mousse Visc = 16800 cP @ 10 sec^{-1}, 13°C, 52% Water*
Average Differential SG = 0.099*

* Includes impact of emulsion breaker

Figure 103:

Vortoil Debris Test Series Differential Pressure Across Simplex Strainer vs. Minutes of Debris Addition

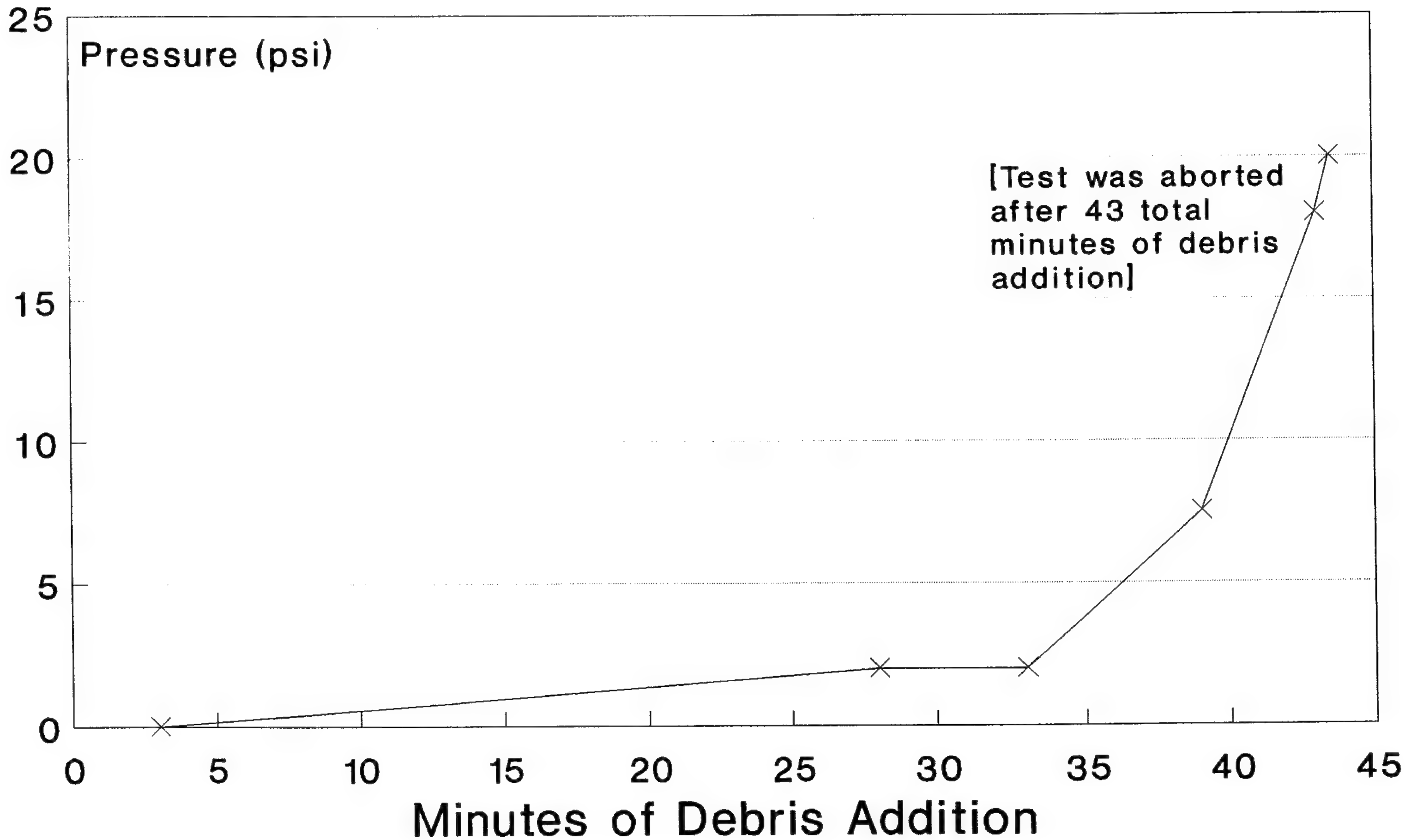


Figure 104a:

Vortoil Debris Test Series
Test #1: 100% Water Influent
196 gpm

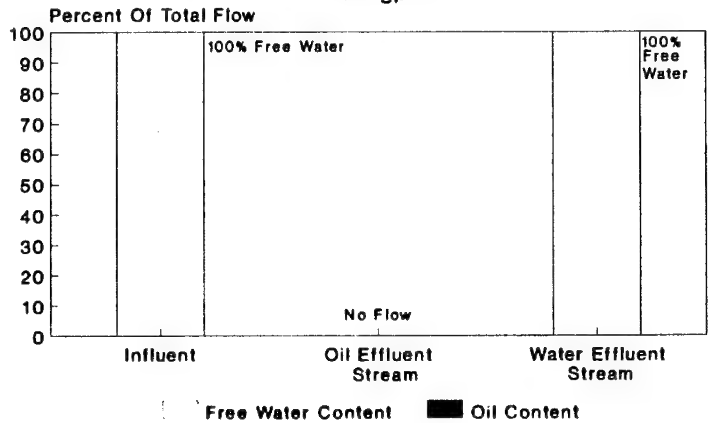


Figure 104b:

Vortoil Debris Test Series
Test #2, Period #1: 55% Influent Oil Content With Debris
220 gpm for 10.0 Minutes

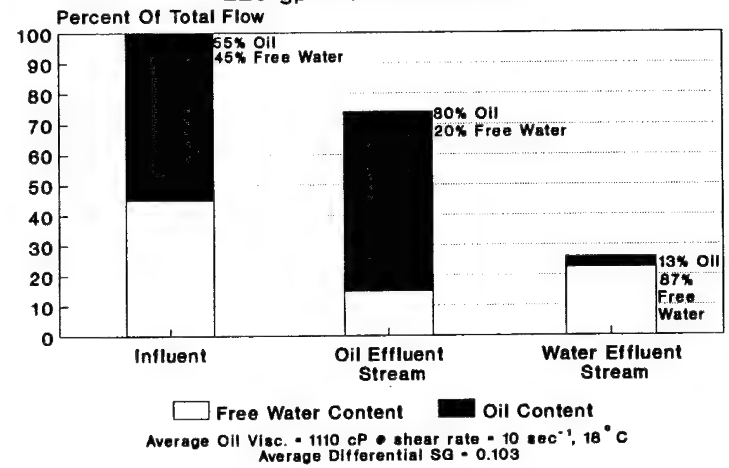


Figure 104c:

Vortoil Debris Test Series
Test #2, Period #2: 55% Influent Oil Content With Debris
228 gpm for 10.0 Minutes

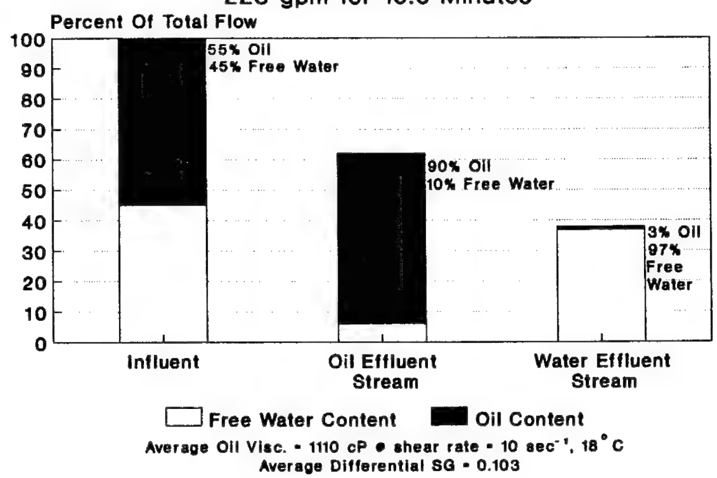


Figure 104d:

Vortoil Debris Test Series
Test #2, Period #3: 55% Influent Oil Content With Debris
218 gpm for 10.0 Minutes

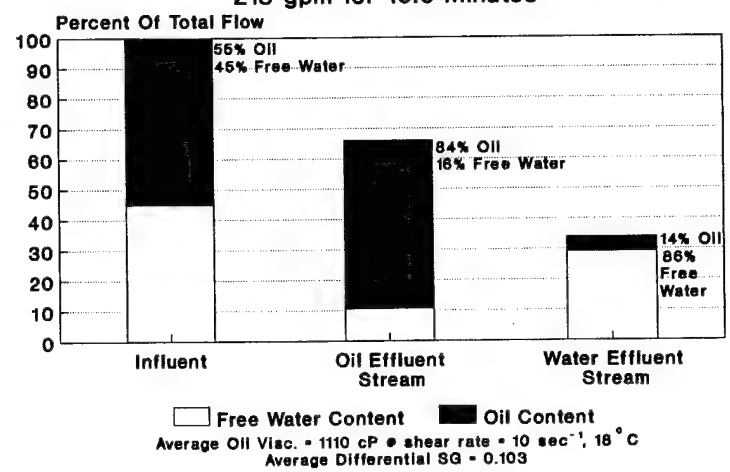


Figure 104e:
Vortoil Debris Test Series
Test #2, Period #4: 60% Influent Oil Content With Debris
227 gpm for 10.0 Minutes

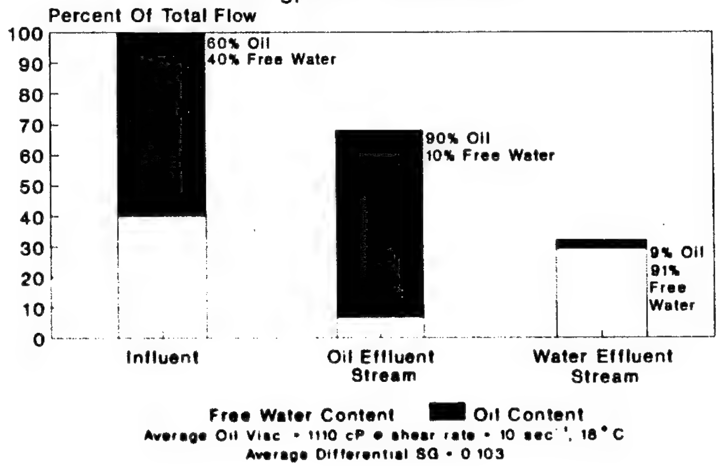


Figure 104f:
Vortoil Debris Test Series
Test #2, Period #5: 56% Influent Oil Content With Debris
237 gpm for 3.5 Minutes

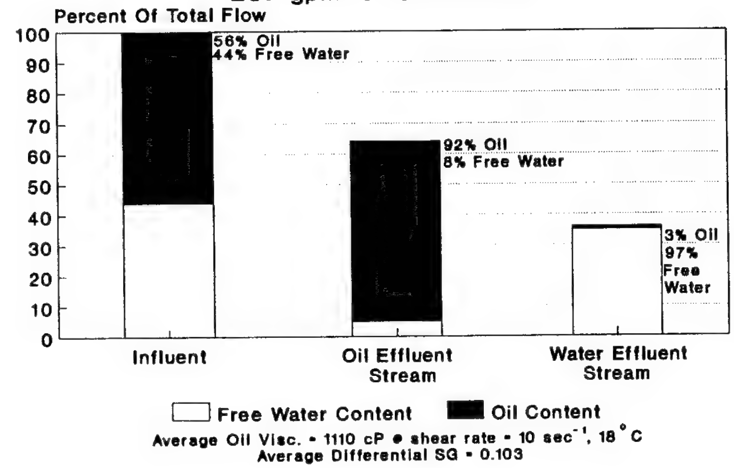


Figure 104g:
Vortoil Debris Test Series
Test #2, Average: 56% Influent Oil Content With Debris
at 224 gpm (avg) for 43.5 Minutes

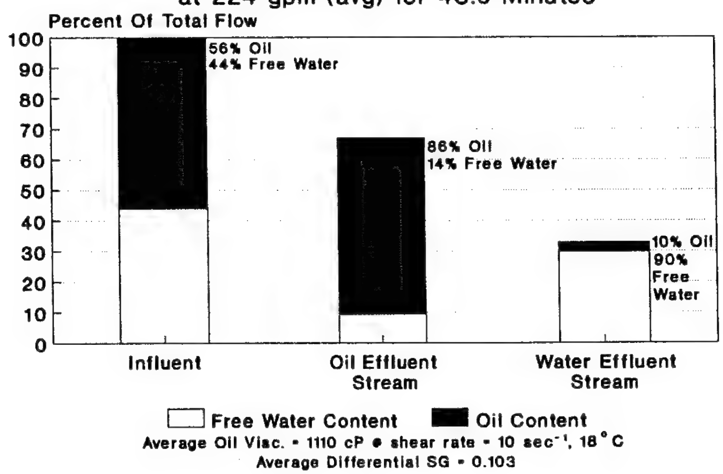
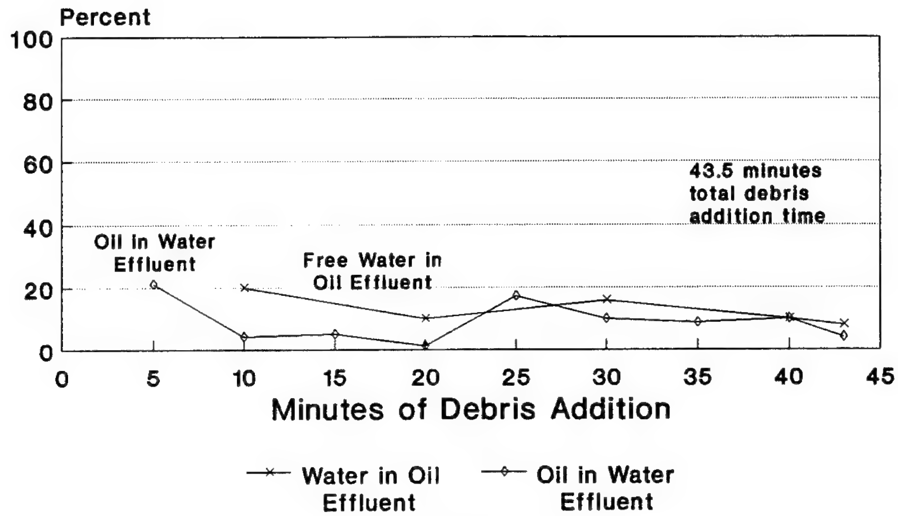


Figure 105:

Vortoil Debris Test Series

Effluent Composition vs. Minutes of Debris Addition



Average Flow Rate = 224 gpm

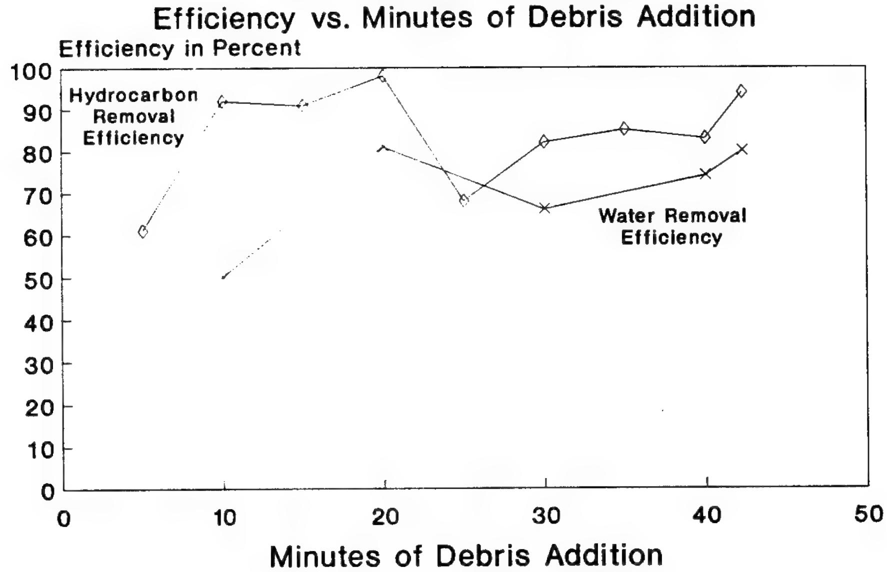
Average Oil Visc. = 1110 cP @ shear rate = 10^{-1} sec, 18° C

Average Diff. SG = 0.103

Figure 106:

Vortoil Debris Test Series

Efficiency vs. Minutes of Debris Addition



Average Flow Rate = 224 gpm

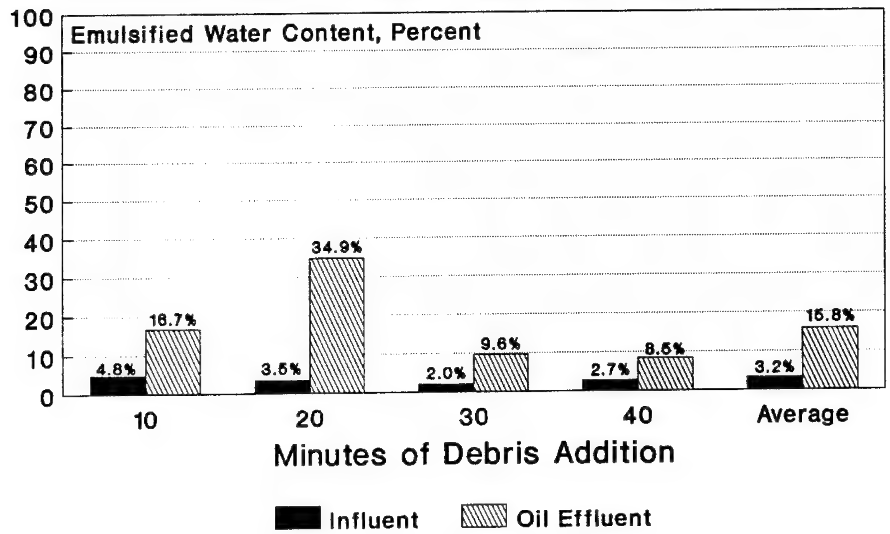
Average Oil Visc. = 1110 cP @ shear rate = 10 sec^{-1}, 18° C

Average Differential SG = 0.103

Figure 107:

Vortoil Debris Test Series

Emulsified Water Content Before and After Separation



Average Flow Rate = 224 gpm
Average Influent Oil Content = 56%
Average Oil Visc. = 1110 cP @ shear rate = 10 sec^{-1}, 18 °C
Average Diff. SG = 0.103

Figure 108:

Vortoil Debris Test Series

Influent and Water Effluent Line Pressure, and Differential Pressure Across Simplex Strainer vs. Time

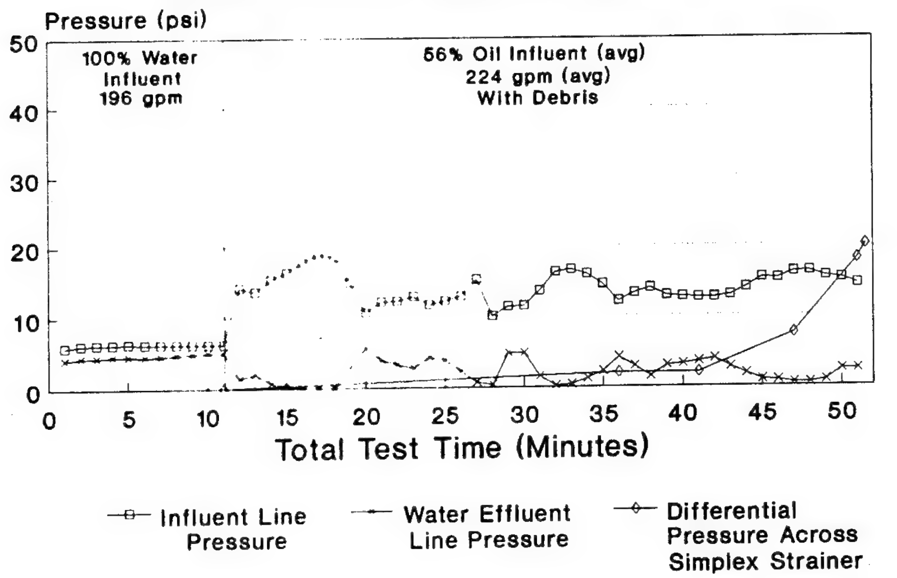
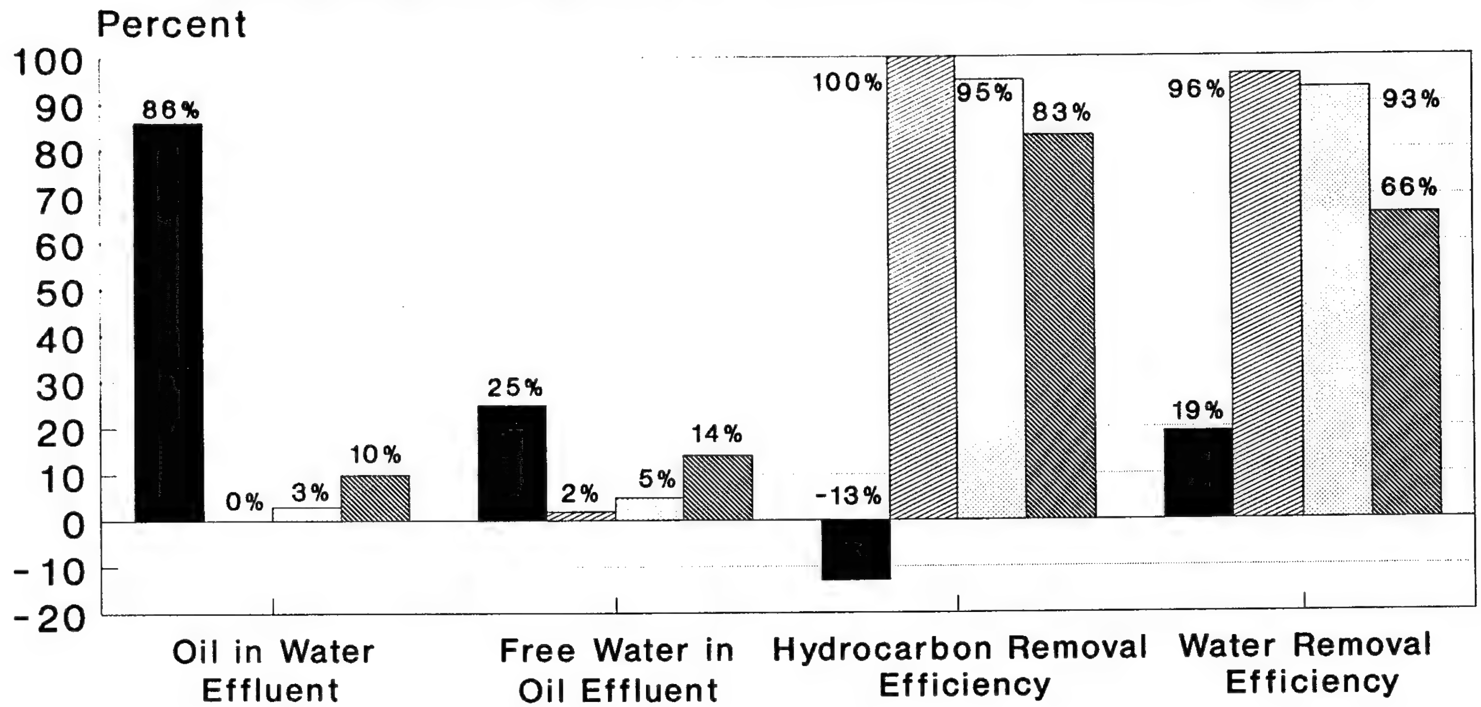


Figure 109:

Impact of Debris on Vortoil: Comparison of Performance to Other Tests at Similar Influent Oil or Mousse Percentages



* Data for this phase of the Crude Oil Test is suspect - see text or Table 14]

All viscosity measurements taken at shear rate = 10 sec^{-1}

Figure 110: Intr-Septor 250 on Test Platform

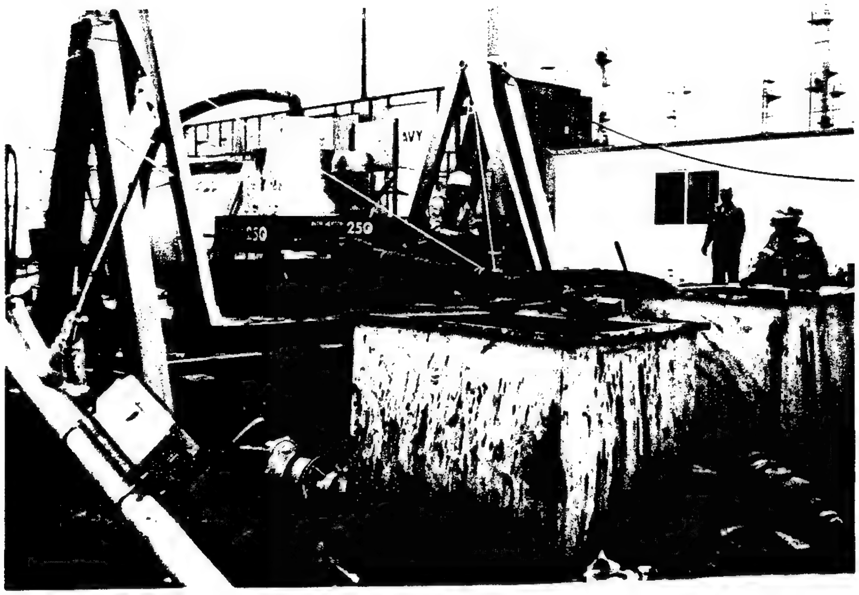
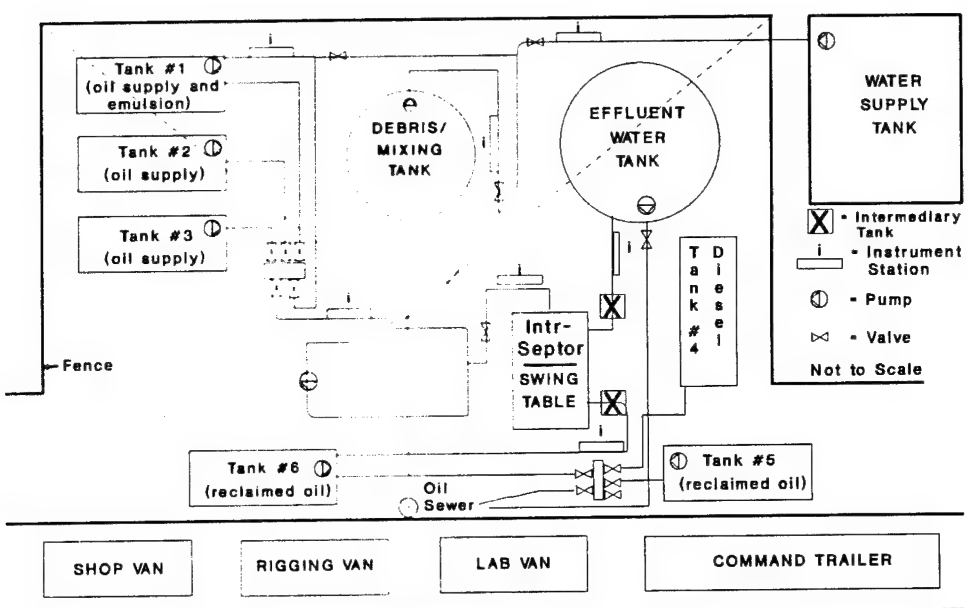
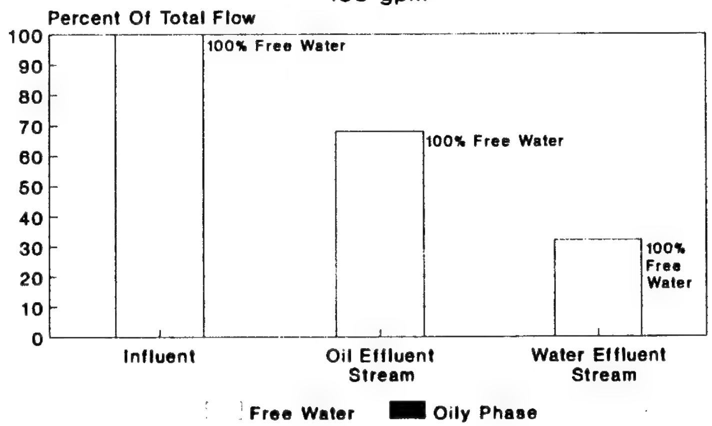


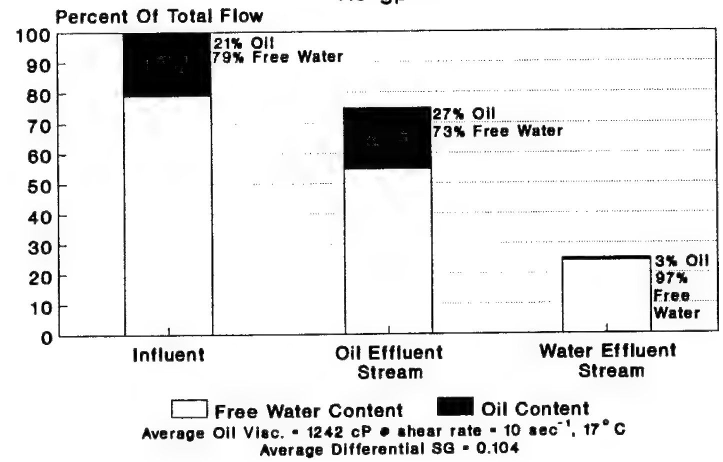
Figure 111: Test Facility Set-Up for Intr-Septor



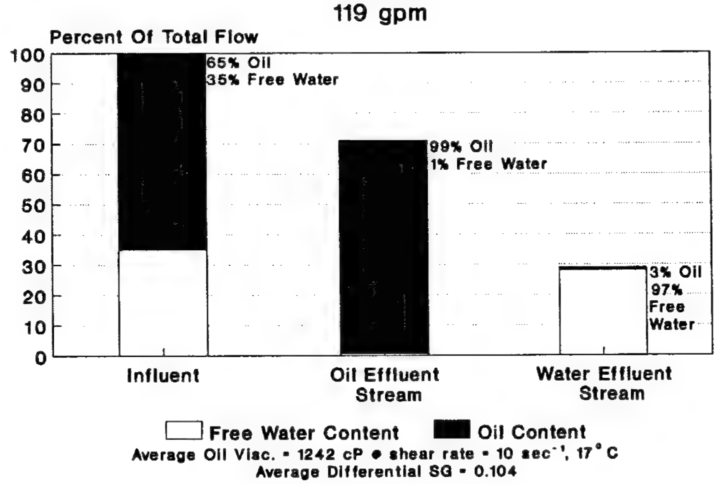
<u>Figure 112a:</u>
Intr-Septor Crude Oil Test Series
Test #1: 100% Water Influent
133 gpm



<u>Figure 112b:</u>
Intr-Septor Crude Oil Test Series
Test #2: 21% Influent Oil Content
119 gpm



<u>Figure 112c:</u>
Intr-Septor Crude Oil Test Series
Test #3: 65% Influent Oil Content
119 gpm



<u>Figure 112d:</u>
Intr-Septor Crude Oil Test Series
Test #4: 61% Influent Oil Content
123 gpm

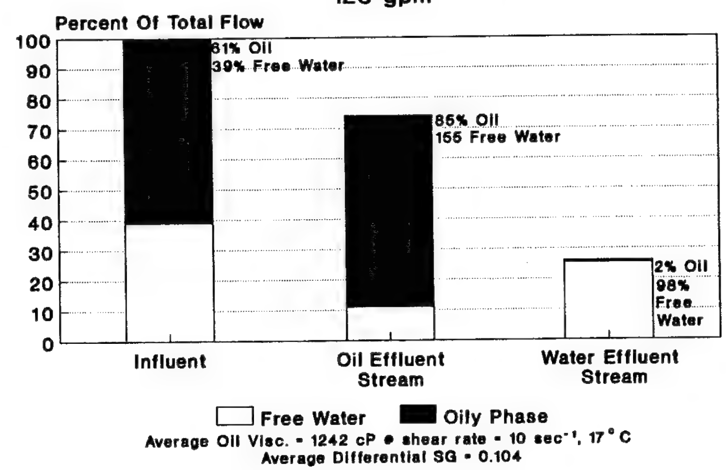
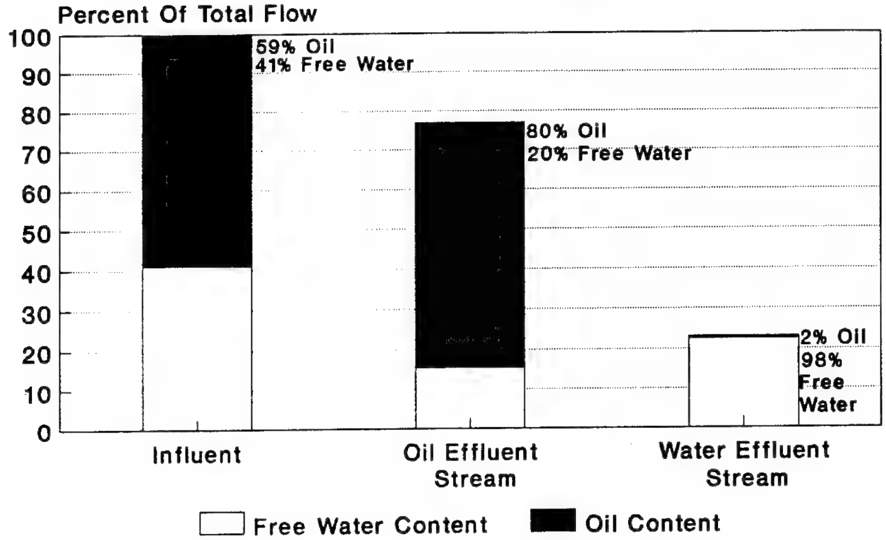


Figure 112e:

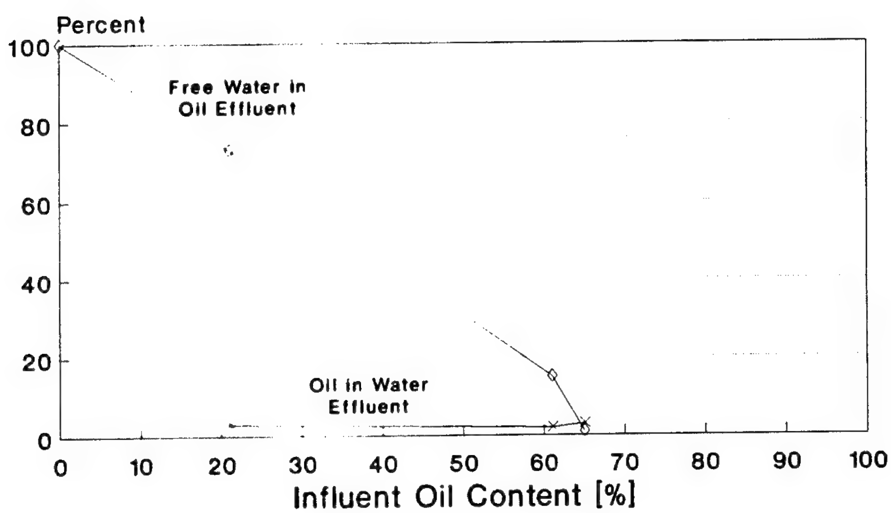
Intr-Septor Crude Oil Test Series
Test #6: 59% Influent Oil Content With Sea Motion at 109 gpm



Average Oil Visc. = 1242 cP @ shear rate = 10 sec^{-1}, 17° C
Averagae Differential SG = 0.104

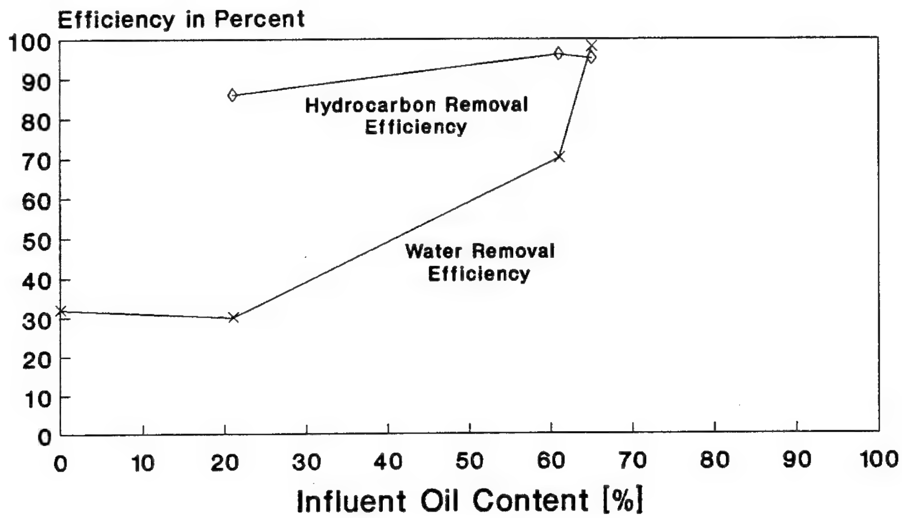
Figure 113:

Intr-Septor Crude Oil Test Series
Effluent Composition vs. Influent Oil Content



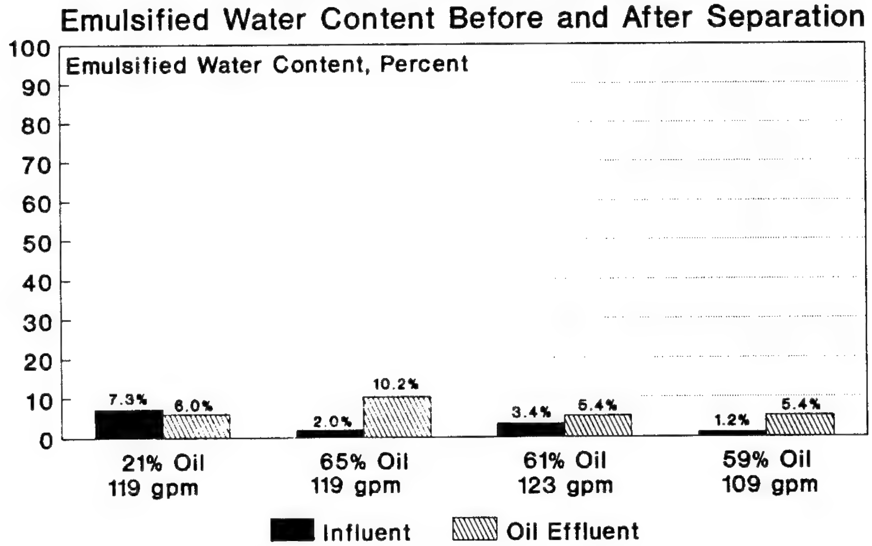
Average Flow Rate = 124 gpm
Average Oil Visc. = 1242 cP @ shear rate = 10 sec^{-1}, 17° C
Average Differential SG = 0.104

Figure 114:
Intr-Septor Crude Oil Test Series
Efficiency vs. Influent Oil Content



Average Flow Rate = 124 gpm
Average Oil Visc. = 1242 cP @ shear rate = 10 sec^{-1}, 17 °C
Average Differential SG = 0.104

Figure 115:
Intr-Septor Crude Oil Test Series
Emulsified Water Content Before and After Separation



Average Flow Rate = 124 gpm
Average Oil Visc. = 1242 cP @ shear rate = 10 sec^{-1}, 17 °C
Average Differential SG = 0.104

Figure 116:

Intr-Septor Crude Oil Test Series
Influent Line Pressure vs. Time

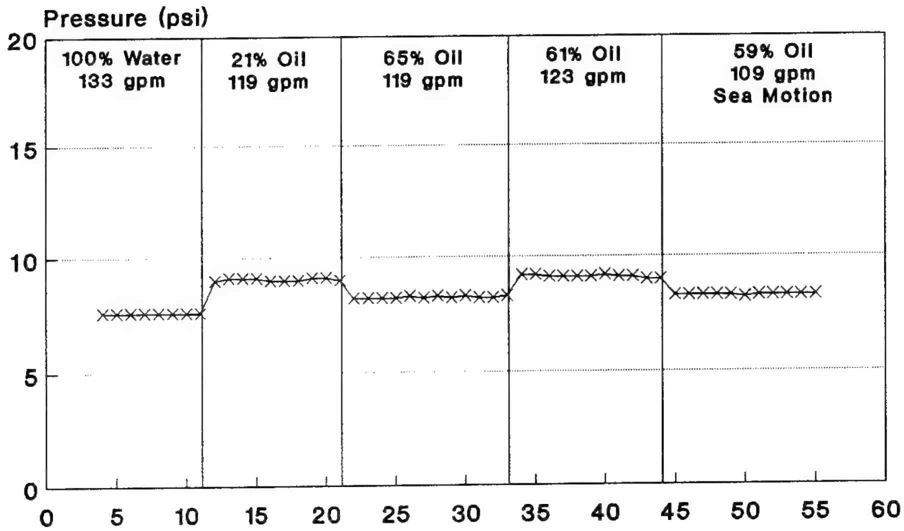


Figure 117:

Impact of Sea Motion on Intr-Septor
Comparison to Stationary Test Results

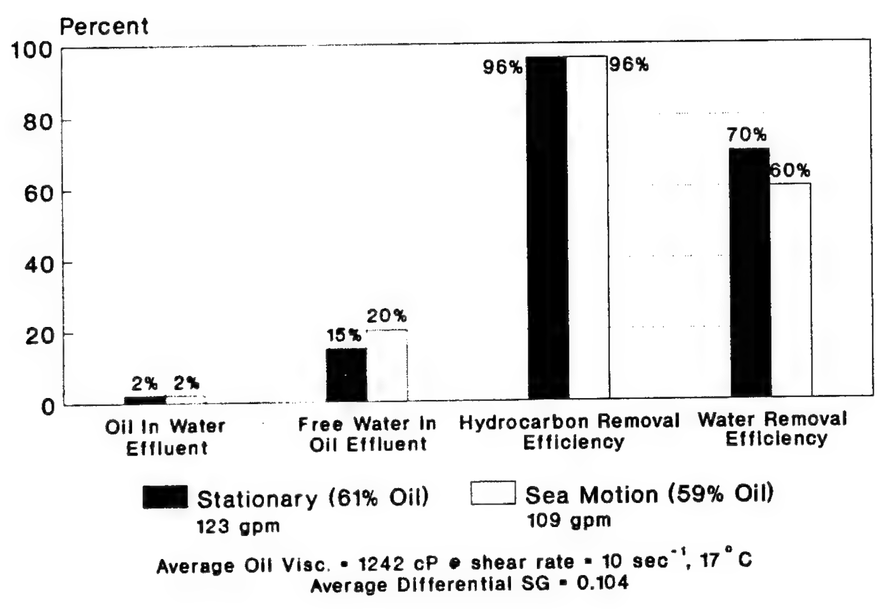


Figure 118a:

Intr-Septor Mousse Test Series
Test #1: 100% Water Influent
128 gpm

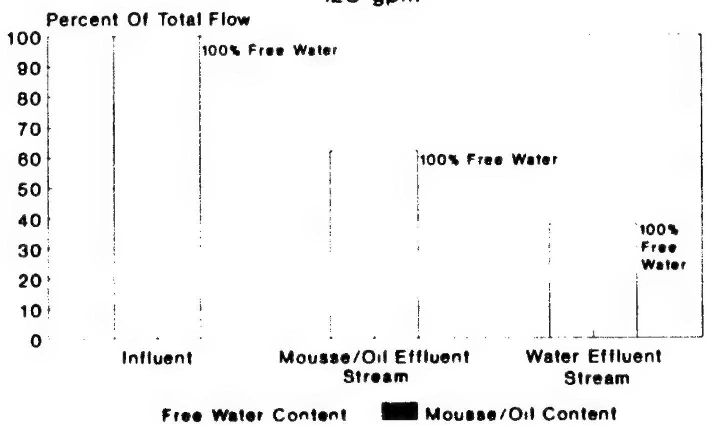
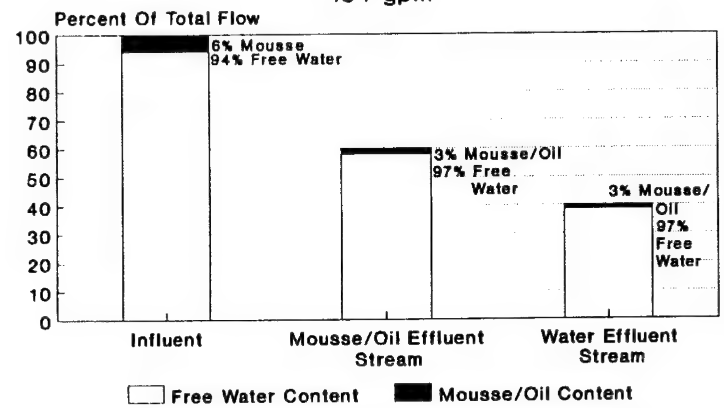


Figure 118b:

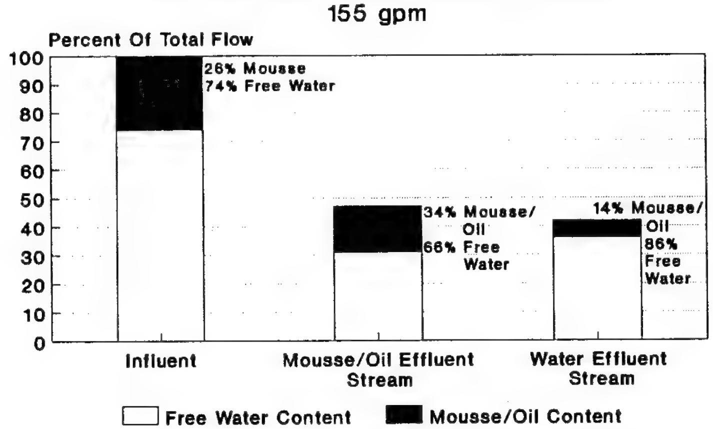
Intr-Septor Mousse Test Series
Test #2: 6% Influent Mousse Content
134 gpm



Avg Influent Mousse Viscosity - 26300 cP @ 10 sec^{-1}, 16° C
Average Water Content of Influent Mousse - 66%
Average Differential SG - 0.101

Figure 118c:

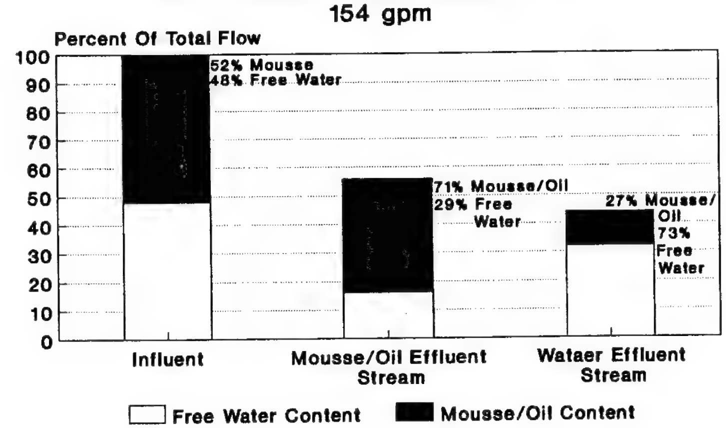
Intr-Septor Mousse Test Series
Test #3: 26% Influent Mousse Content
155 gpm



Avg Influent Mousse Viscosity - 26300 cP @ 10 sec^{-1}, 16° C
Average Water Content of Influent Mousse - 66%
Average Differential SG - 0.101

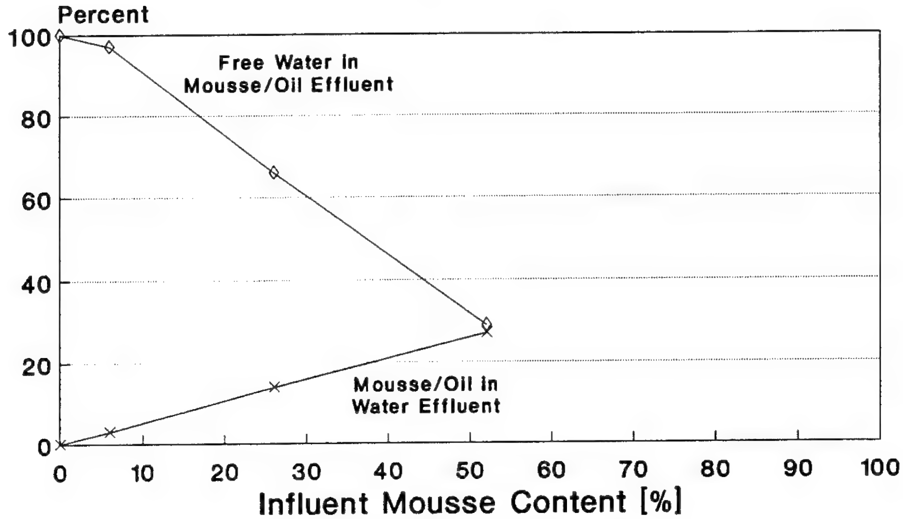
Figure 118d:

Intr-Septor Mousse Test Series
Test #4: 52% Influent Mousse Content
154 gpm



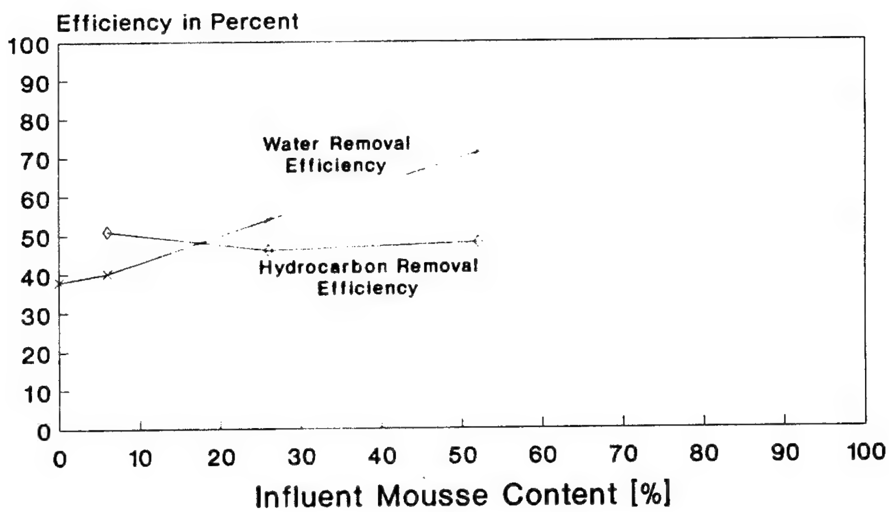
Avg Influent Mousse Viscosity - 26300 cP @ 10 sec^{-1}, 16° C
Average Water Content of Influent Mousse - 66%
Average Differential SG - 0.101

Figure 119:
Intr-Septor Mousse Test Series
Effluent Composition vs. Influent Mousse Content



Average Flow Rate = 143 gpm
Avg Infl Mousse Visc = 26300 cP @ 10 sec^{-1}, 16° C, 66% Water
Average Differential SG = 0.101

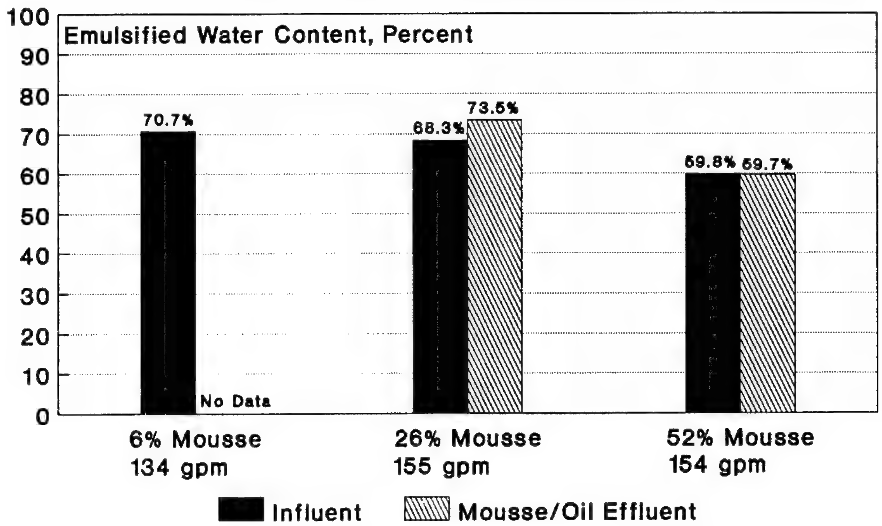
Figure 120:
Intr-Septor Mousse Test Series
Efficiency vs. Influent Mousse Content



Average Flow Rate = 143 gpm
Avg Infl Mousse Visc = 26300 cP @ 10 sec^{-1}, 16° C, 66% Water
Average Differential SG = 0.101

Figure 121:

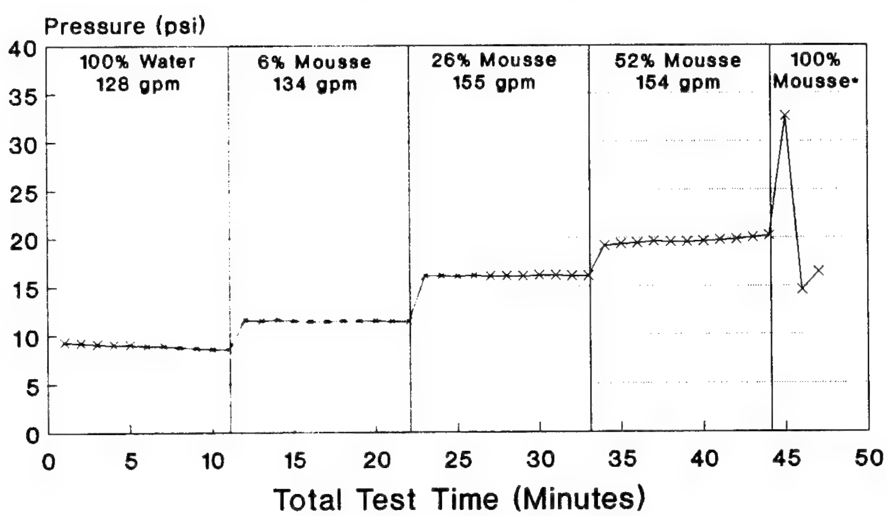
Intr-Septor Mousse Test Series
Emulsified Water Content Before and After Separation



Average Flow Rate = 143 gpm
Average Mousse Visc = 26300 cP @ shear rate = 10 sec^{-1}, 16°C
Average Differential SG = 0.101

Figure 122:

Intr-Septor Mousse Test Series
Influent Line Pressure vs. Time



*100% Mousse phase cancelled due to problems with test facility equipment.

Figure 123:

Impact of Mousse on Intr-Septor
Comparison of Mousse/Oil Content of
Water Effluent for Crude Oil and Mousse Test Series

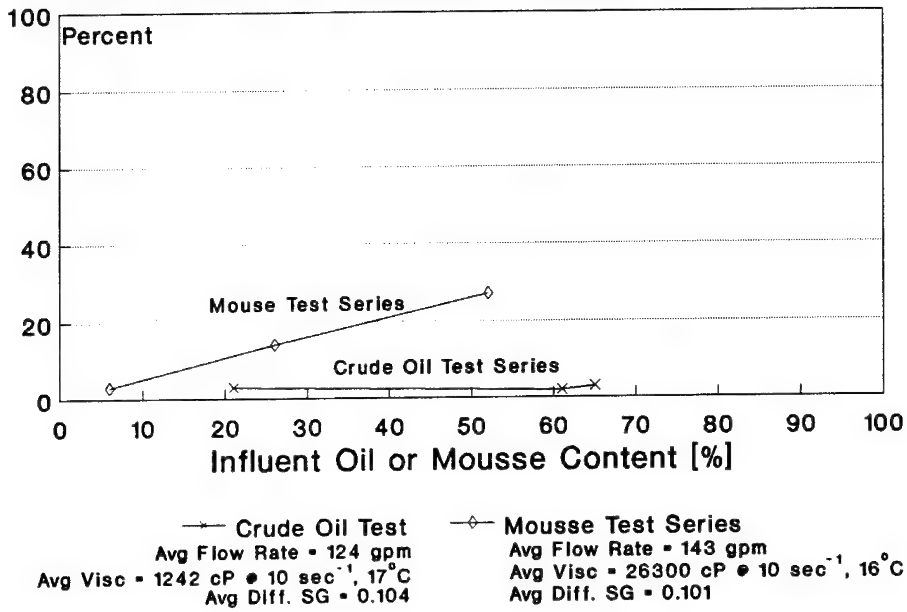


Figure 124:

Impact of Mousse on Intr-Septor:
Comparison of Free Water in Oil Effluent
for Crude Oil and Mousse Test Series

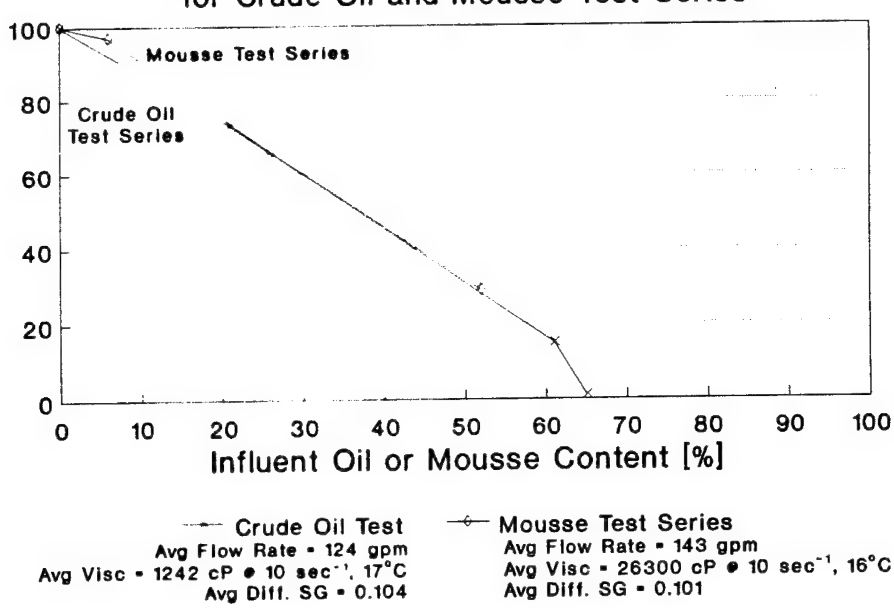


Figure 125:

Impact of Mousse on Intr-Septor:
Comparison of Water Removal Efficiency
for Crude Oil and Mousse Test Series

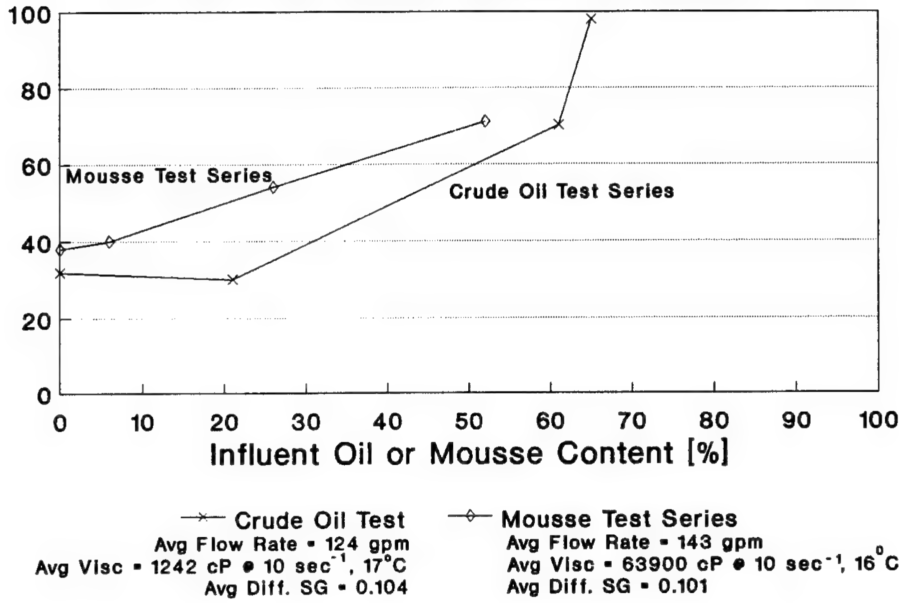


Figure 126:

Impact of Mousse on Intr-Septor:
Comparison of Hydrocarbon Removal
Efficiency for Crude Oil and Mousse Test Series

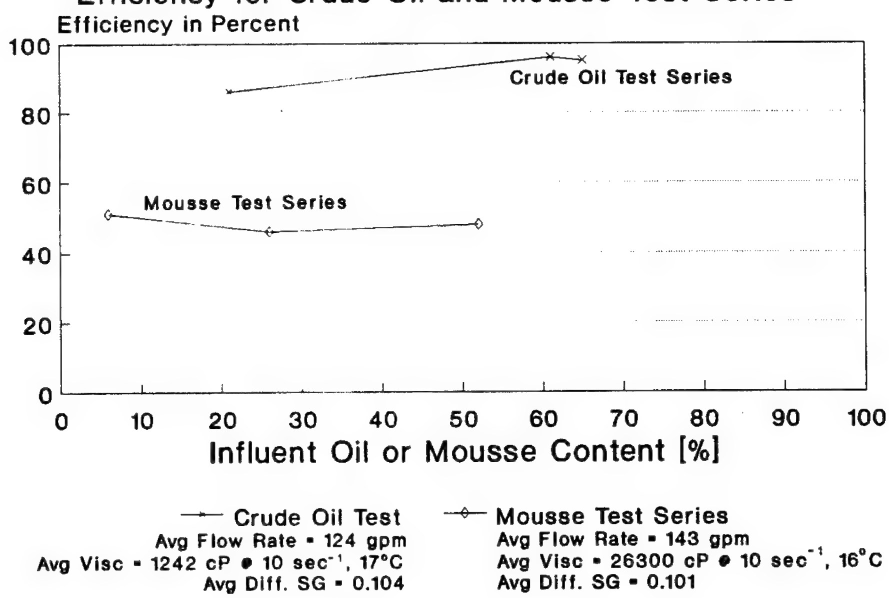


Figure 127a:
Intr-Septor Mousse With Emulsion Breaker Test Series
Test #1: 100% Water Influent
131 gpm

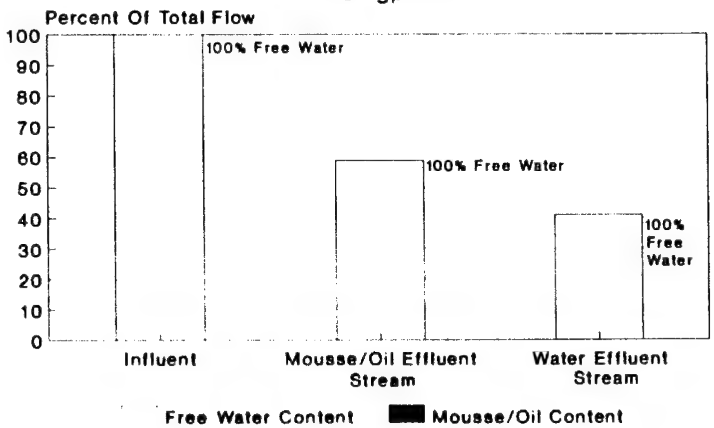


Figure 127b:
Intr-Septor Mousse With Emulsion Breaker Test Series
Test #2: 4% Influent Mousse Content
129 gpm

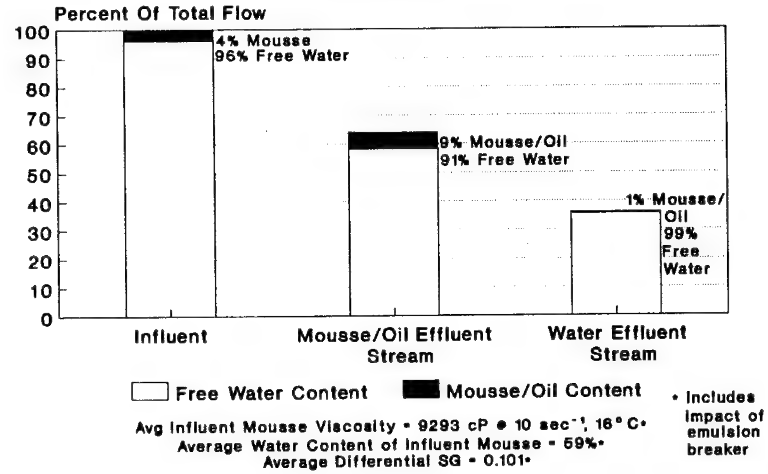


Figure 127c:
Intr-Septor Mousse With Emulsion Breaker Test Series
Test #3: 39% Influent Mousse Content
132 gpm

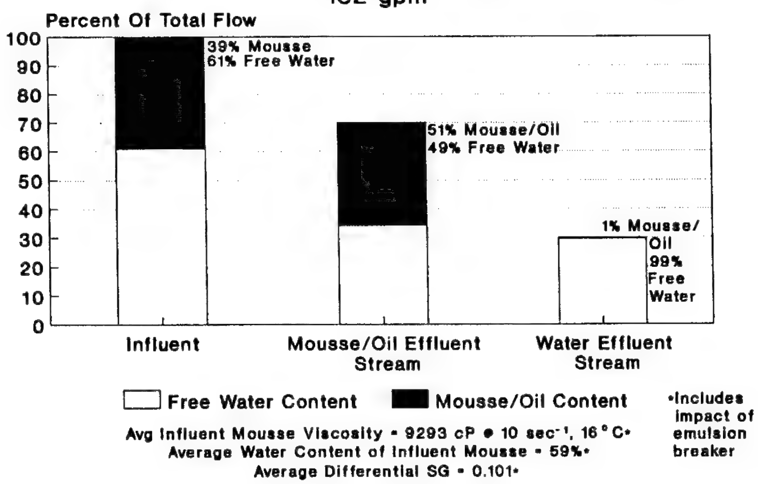


Figure 127d:
Intr-Septor Mousse With Emulsion Breaker Test Series
Test #4: 57% Influent Mousse Content
138 gpm

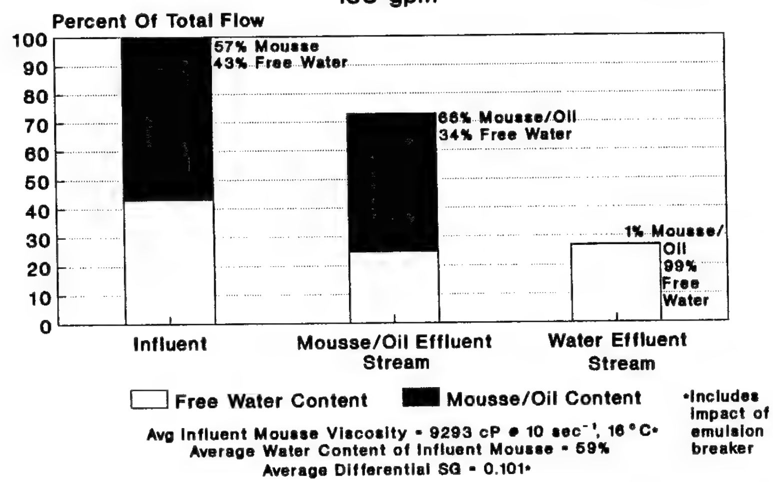
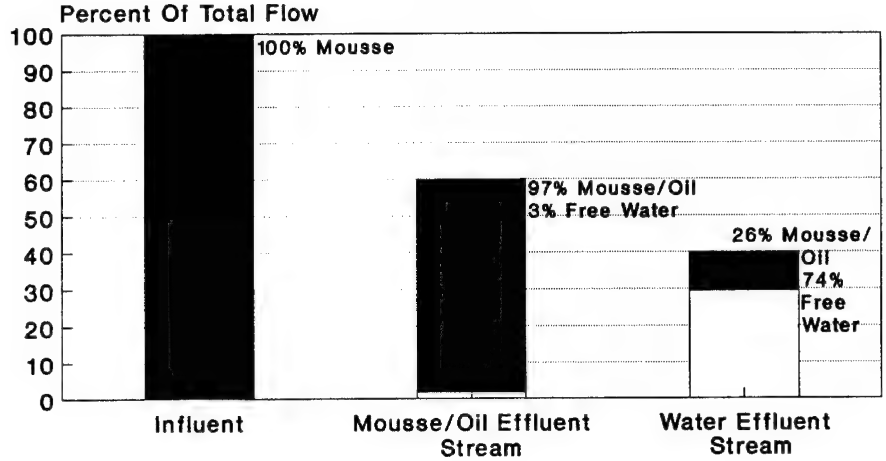


Figure 127e:

Intr-Septor Mousse With Emulsion Breaker Test Series
Test# 5: 100% Mousse Influent
172 gpm

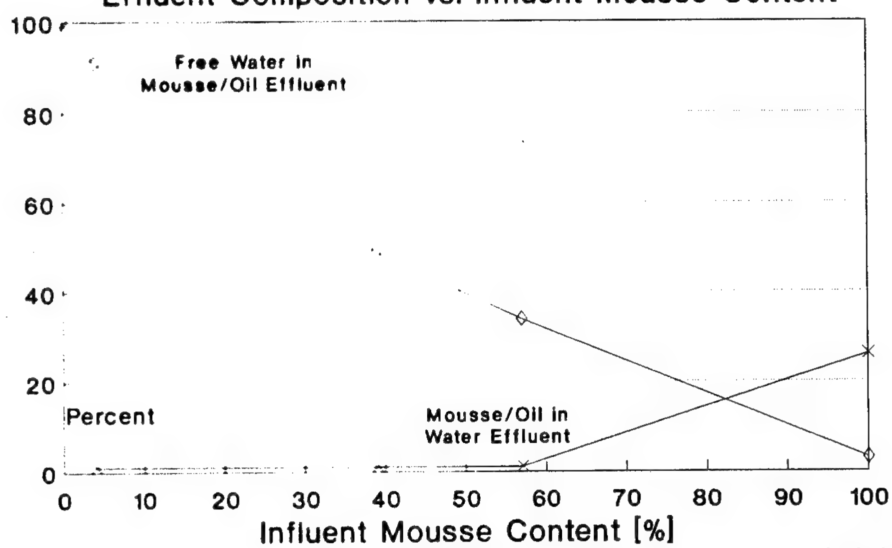


Avg Influent Mousse Viscosity = 9293 cP @ 10 sec^{-1}, 16° C*
Average Water Content of Influent Mousse = 59%*
Average Differential SG = 0.101*

* Includes impact of emulsion breaker

Figure 128:

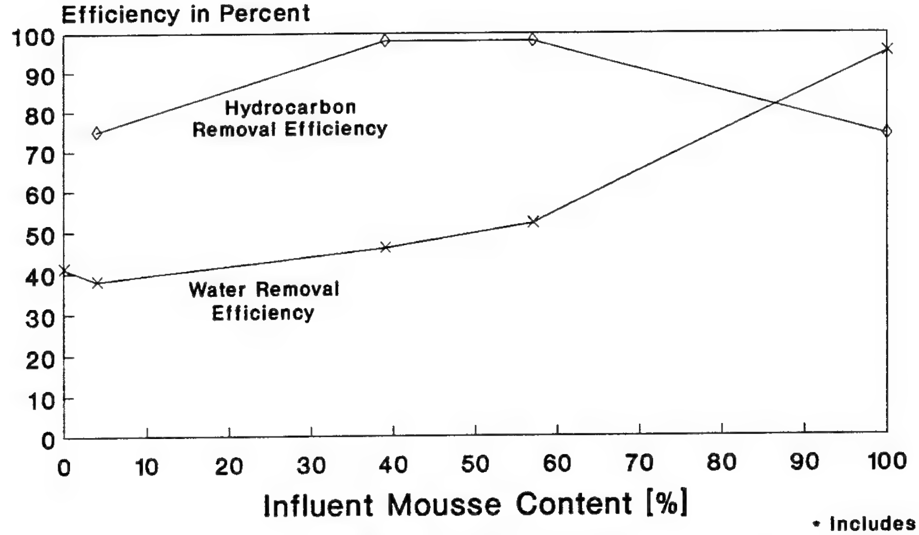
Intr-Septor Mousse With Emulsion Breaker Test Series
Effluent Composition vs. Influent Mousse Content



Average Flow Rate = 140 gpm
Avg Infl Mousse Visc = 9293 cP @ 10 sec^{-1}, 16 °C, 59% Water*
Average Differential SG = 0.101*

*Includes impact of emulsion breaker

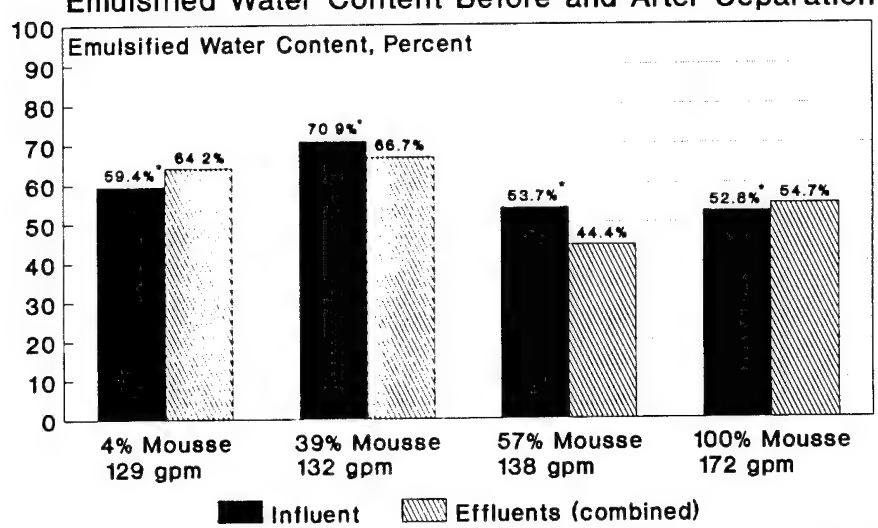
Figure 129:
Intr-Septor Mousse With Emulsion Breaker Test Series
Efficiency vs. Influent Mousse Content



Average Flow Rate = 140 gpm
Avg Infl Mousse Visc = 9293 cP @ 10 sec^{-1}, 16 °C, 59% Water*
Average Differential SG = 0.101*

* Includes impact of emulsion breaker

Figure 130:
Intr-Septor Mousse With Emulsion Breaker Test Series
Emulsified Water Content Before and After Separation



Average Flow Rate = 140 gpm
Avg Infl Mousse Visc = 9293 cP @ 10 sec^{-1}, 16 °C, 59% Water*
Average Differential SG = 0.101*

* Includes impact of emulsion breaker in influent

Figure 131:

Intr-Septor Mousse With Emulsion Breaker Test Series: Impact of Emulsion Breaker on Viscosity

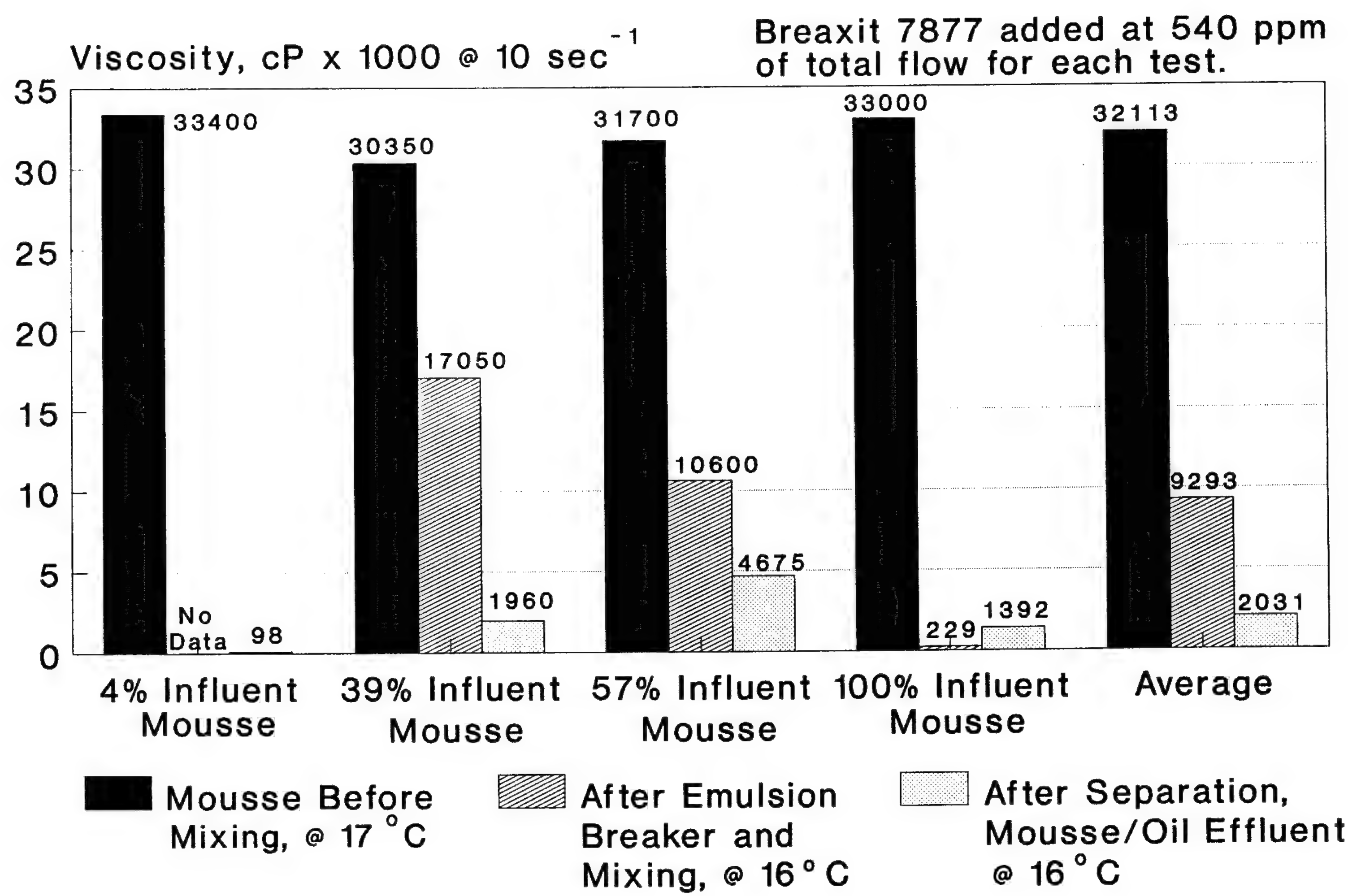


Figure 132:

Intr-Septor Mousse With Emulsion Breaker Test Series
Influent Line Pressure vs. Time

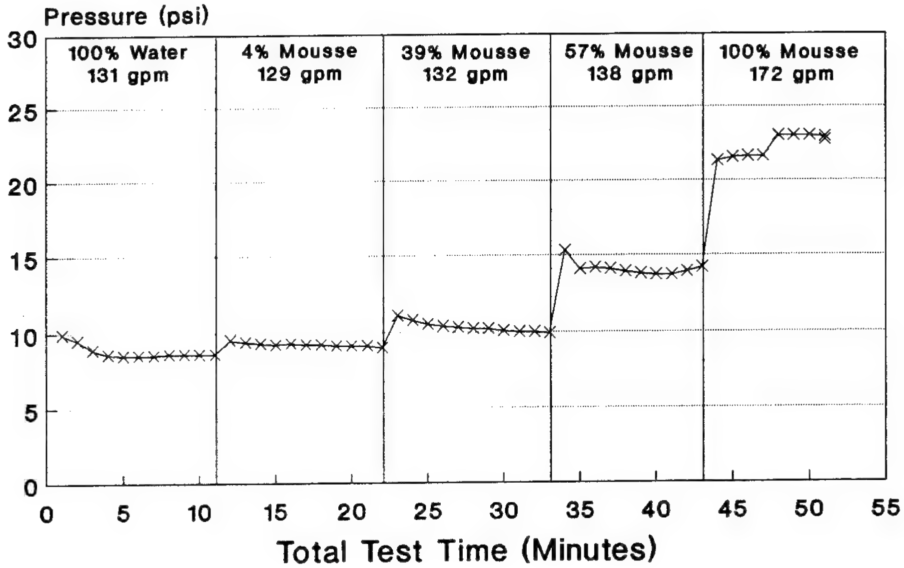


Figure 133:

Impact of Viscosity on Intr-Septor:
Mousse or Oil Effluent Rate vs. Viscosity

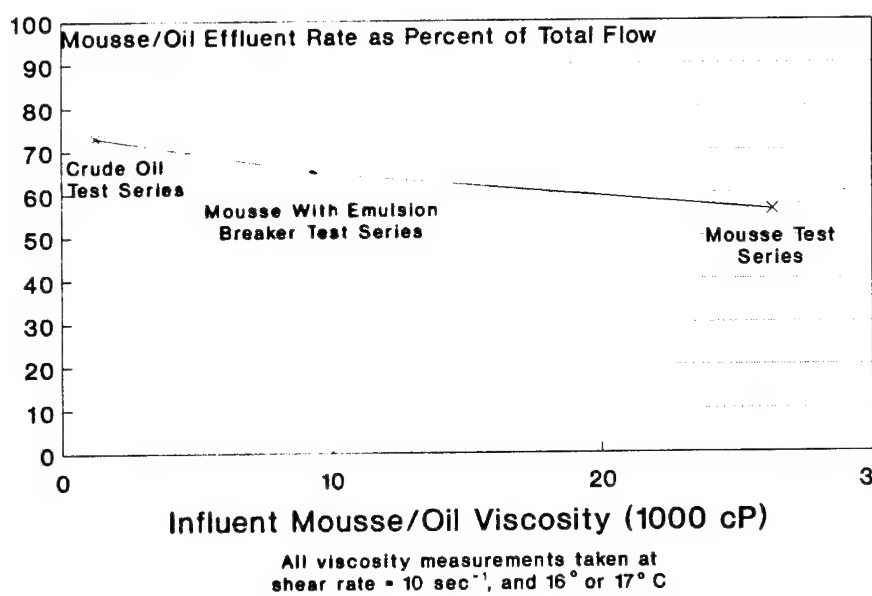


Figure 134:

Impact of Emulsion Breaker on Intr-Septor: Comparison of Mousse/Oil Content of Water Effluent for Mousse and Mousse With Emulsion Breaker Test Series

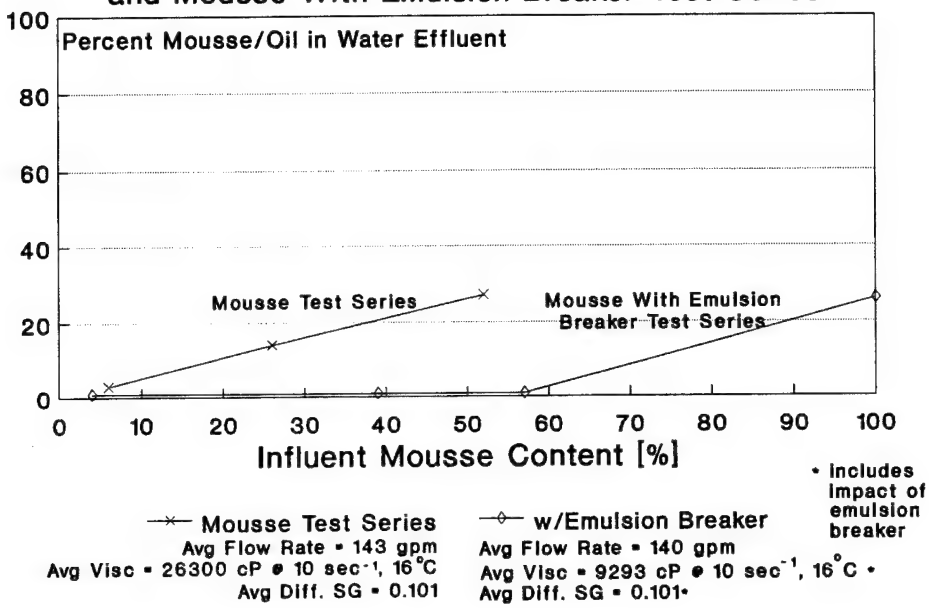


Figure 135:

Impact of Emulsion Breaker on Intr-Septor: Comparison of Free Water Content of Mousse/Oil Effluent for Mousse and Mousse With Emulsion Breaker Test Series

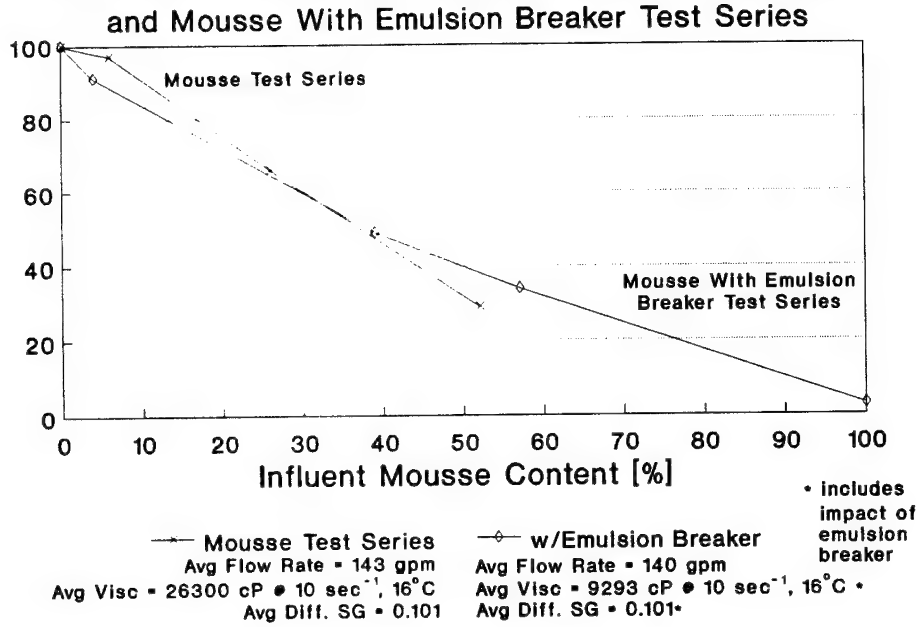


Figure 136:

Impact of Emulsion Breaker on Intr-Septor: Comparison of Water Removal Efficiency for Mousse and Mousse With Emulsion Breaker Test Series

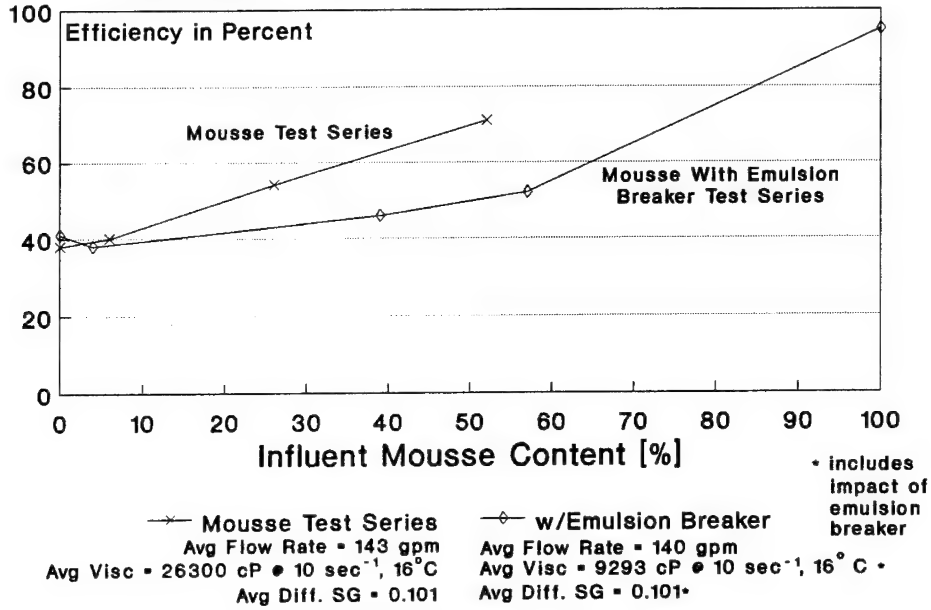
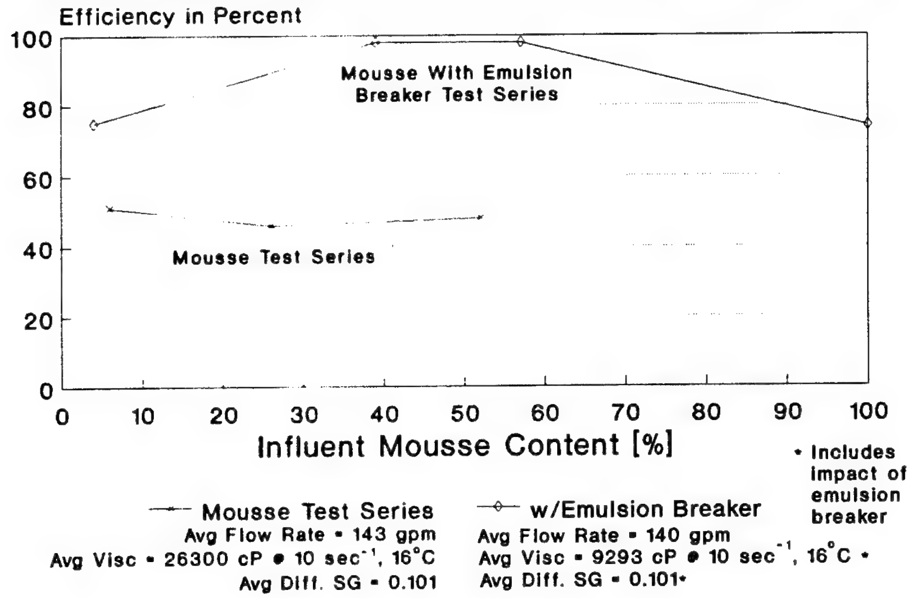


Figure 137:

Impact of Emulsion Breaker on Intr-Septor: Comparison of Hydrocarbon Removal Efficiency for Mousse and Mousse With Emulsion Breaker Test Series



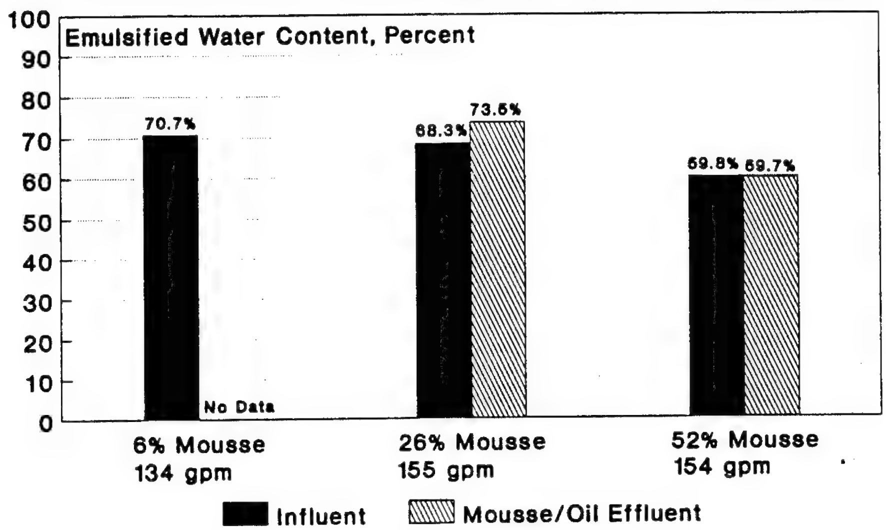


Figure 138:
Intr-Septor Mousse Test Series
Emulsified Water Content Before and After Separation

Average Flow Rate = 143 gpm
Average Mousse Visc = 26300 cP @ shear rate = 10 sec^{-1}, 16°C
Average Differential SG = 0.101

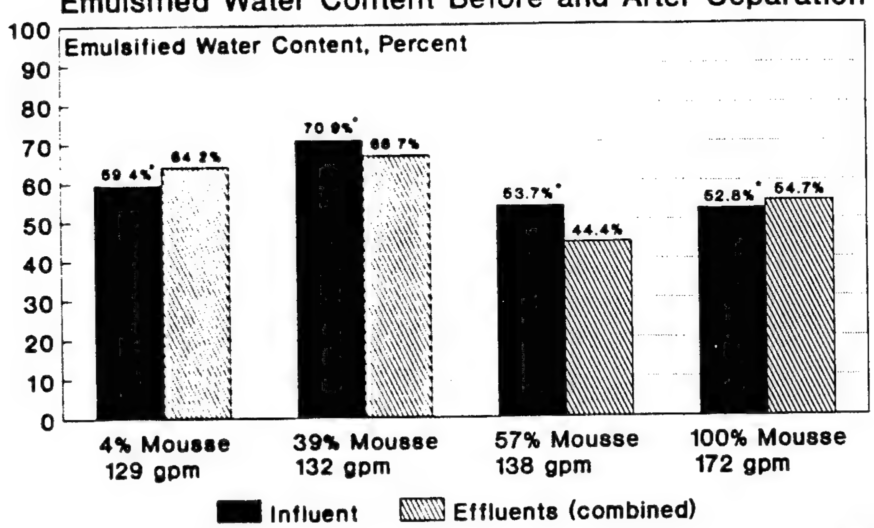


Figure 139:
Intr-Septor Mousse With Emulsion Breaker Test Series
Emulsified Water Content Before and After Separation

Average Flow Rate = 140 gpm
Avg Infl Mousse Visc = 9293 cP @ 10 sec^{-1}, 16°C , 59% Water*
Average Differential SG = 0.101*

* Includes impact of emulsion breaker in influent

Figure 140:

Intr-Septor Debris Test Series
Influent Line Pressure vs. Time

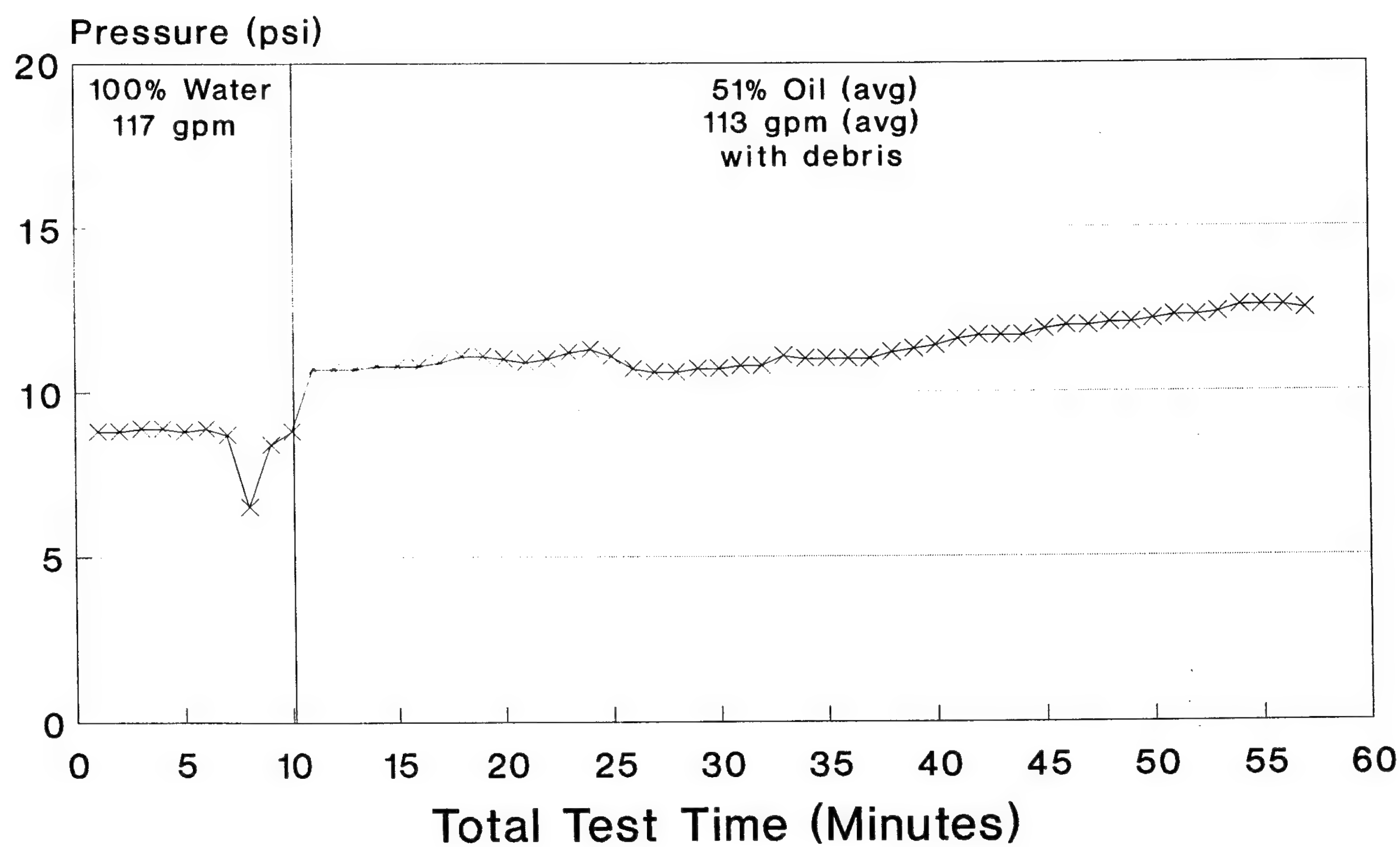


Figure 141a:
Intr-Septor Debris Test Series
Test #1: 100% Water Influent
117 gpm

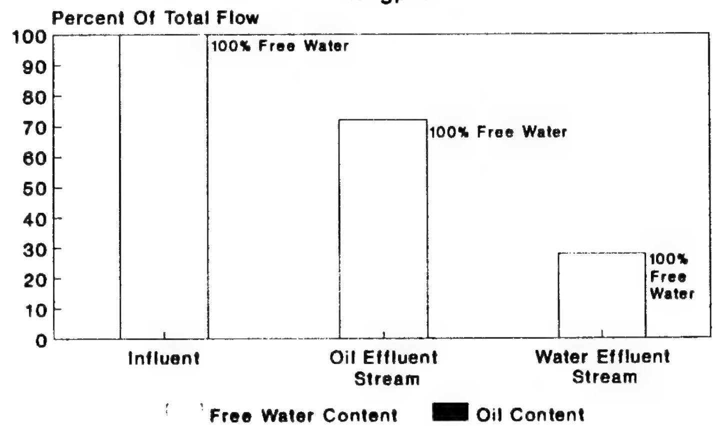


Figure 141b:
Intr-Septor Debris Test Series
Test #2, Period #1: 50% Influent Oil Content
with Debris at 121 gpm for 10.0 Minutes

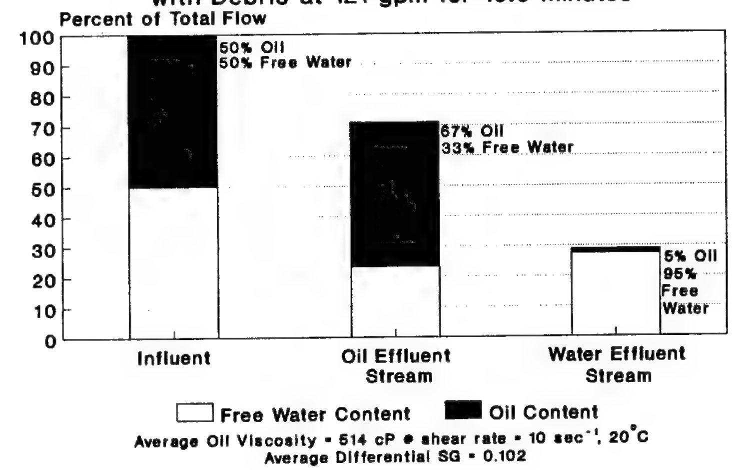


Figure 141c:
Intr-Septor Debris Test Series
Test #2, Period #2: 53% Influent Oil Content
with Debris at 109 gpm for 10.0 Minutes

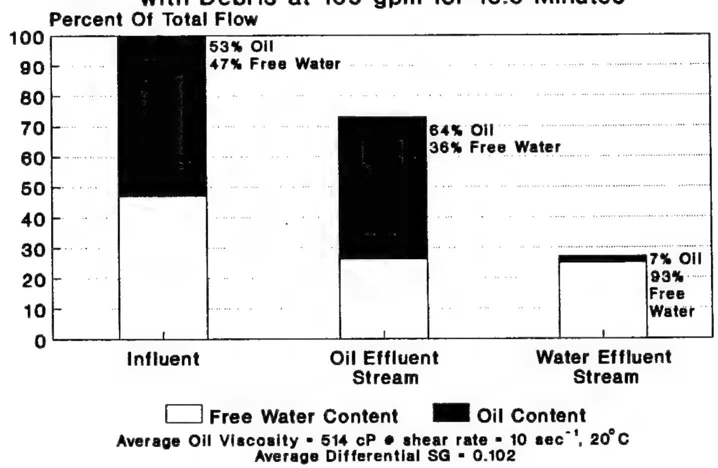


Figure 141d:
Intr-Septor Debris Test Series
Test #2, Period #3: 50% Influent Oil Content
with Debris at 120 gpm for 10.0 Minutes

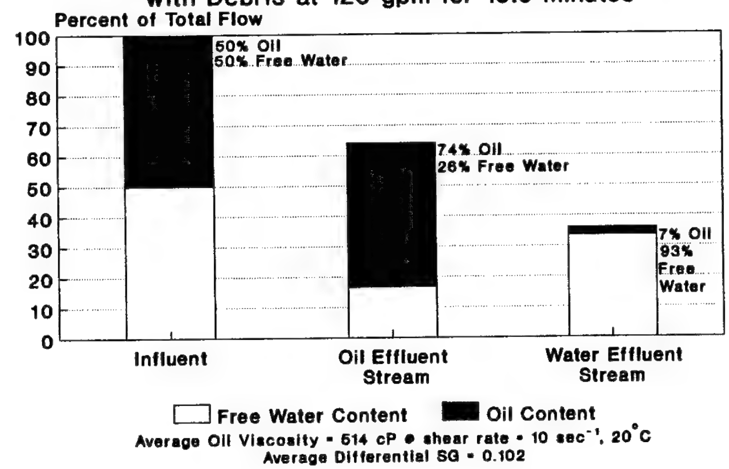
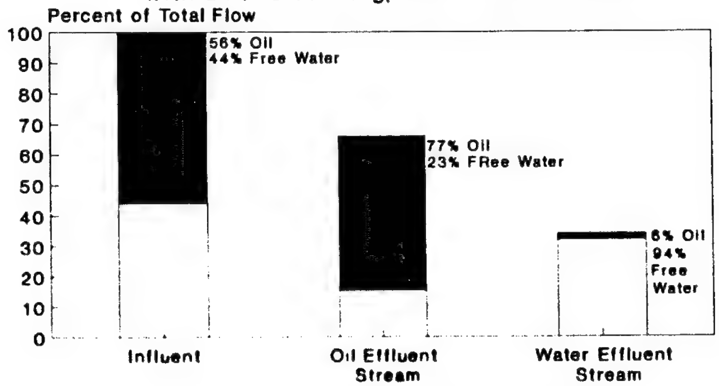


Figure 141e:

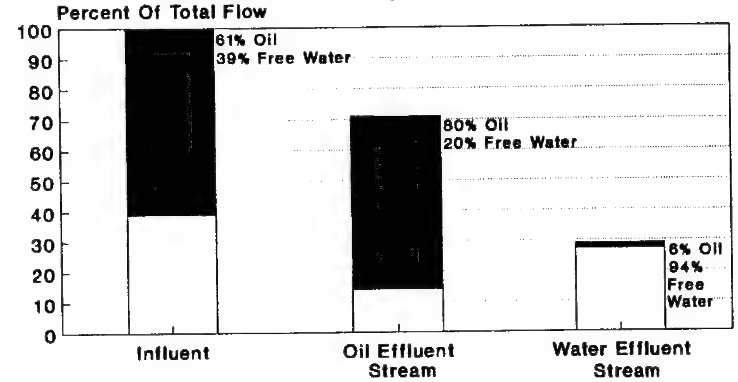
Intr-Septor Debris Test Series
Test #2, Period #4: 56% Influent Oil Content
with Debris at 110 gpm for 10.0 Minutes



Free Water Content   Oil Content
Average Oil Viscosity = 514 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.102

Figure 141f:

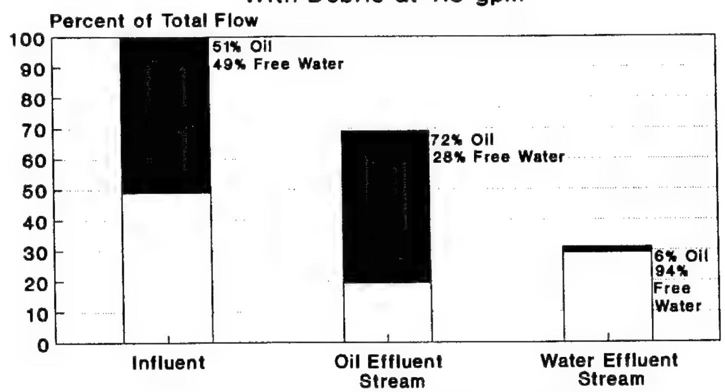
Intr-Septor Debris Test Series
Test #2, Period #5: 61% Influent Oil Content
with Debris at 99 gpm for 5.0 Minutes



Free Water Content   Oil Content
Average Oil Viscosity = 514 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.102

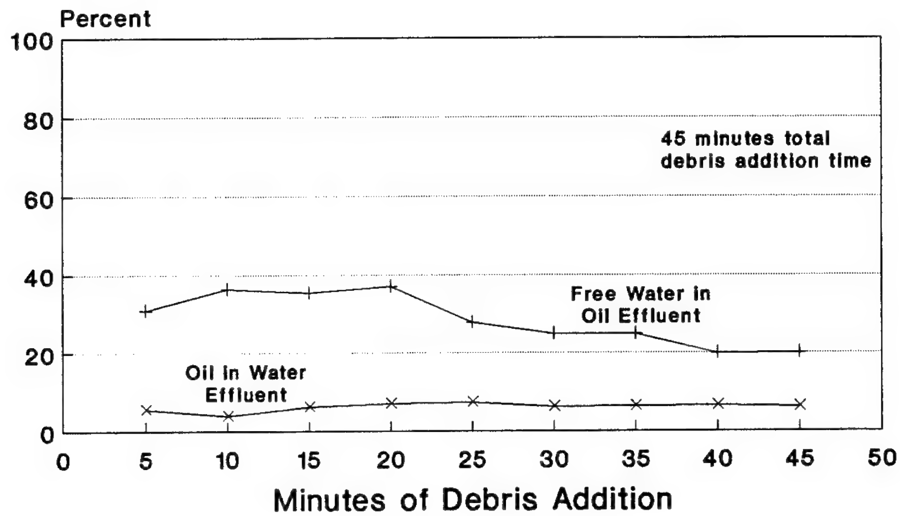
Figure 141g:

Intr-Septor Debris Test Series
Test #2 Average: 53% Influent Oil Content
With Debris at 113 gpm



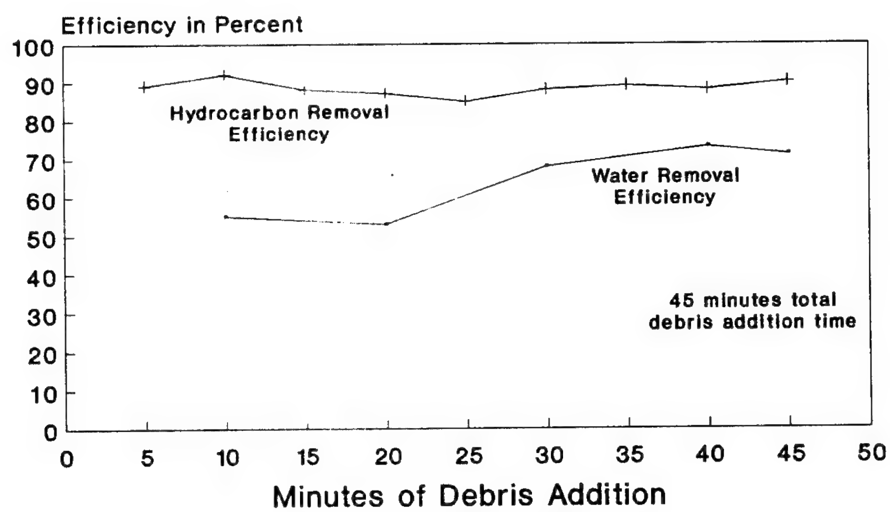
Free Water Content   Oil Content
Average Oil Viscosity = 514 cP @ shear rate = 10 sec^{-1}, 20°C
Average Differential SG = 0.102

Figure 142:
Intr-Septor Debris Test Series
Effluent Composition vs. Minutes of Debris Addition



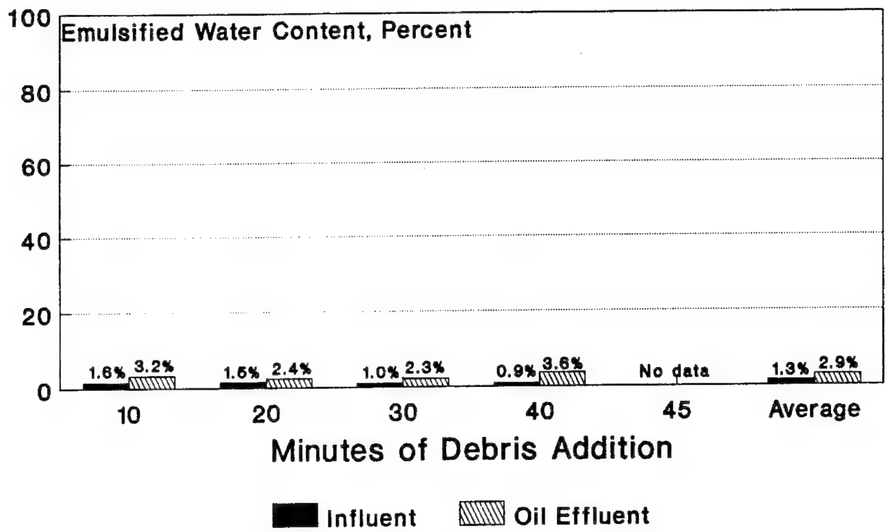
Average Flow Rate = 113 gpm
Avg Infl = 53% Oil, Avg Oil Visc = 514 cP @ 10 sec^{-1}, 20° C
Average Diff. SG = 0.102

Figure 143:
Intr-Septor Debris Test Series
Efficiency vs. Minutes of Debris Addition



Average Influent Oil Content = 51%
Avg Infl = 53% Oil, Avg Oil Visc = 514 cP @ 10 sec^{-1}, 20° C
Average Flow Rate = 113 gpm

Figure 144:
Intr-Septor Debris Test Series
Emulsified Water Content Before and After Separation



Average Flow Rate = 113 gpm
Average Influent Oil Content = 53%
Average Oil Viscosity = 514 cP @ shear rate = 10 sec^{-1}, 20 °C
Average Differential SG = 0.102

Figure 145:
Impact of Debris on Intr-Septor:
Performance Comparison from Crude Oil, Mousse,
Mousse With Emulsion Breaker, and Debris Test Series

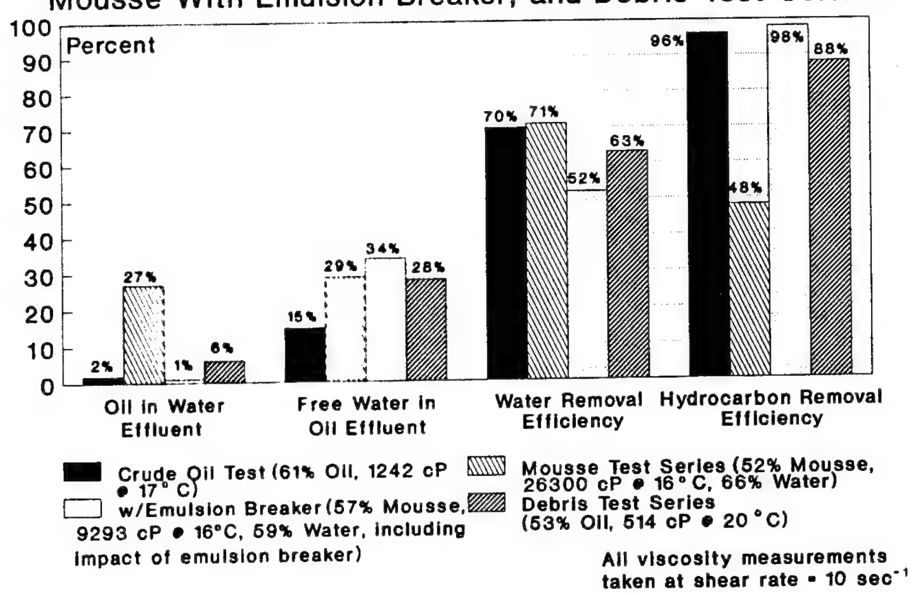


Figure 146:
Separator Comparison:
Ratio of System Weight to Capacity

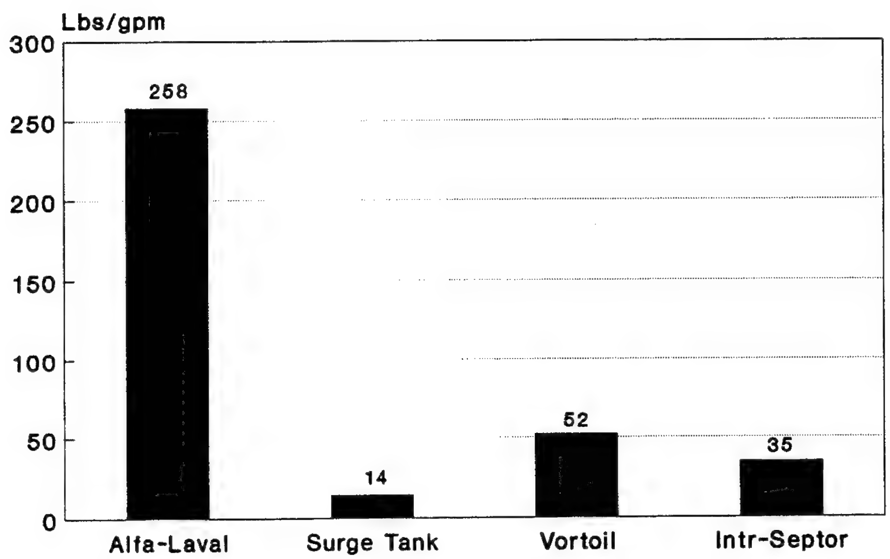
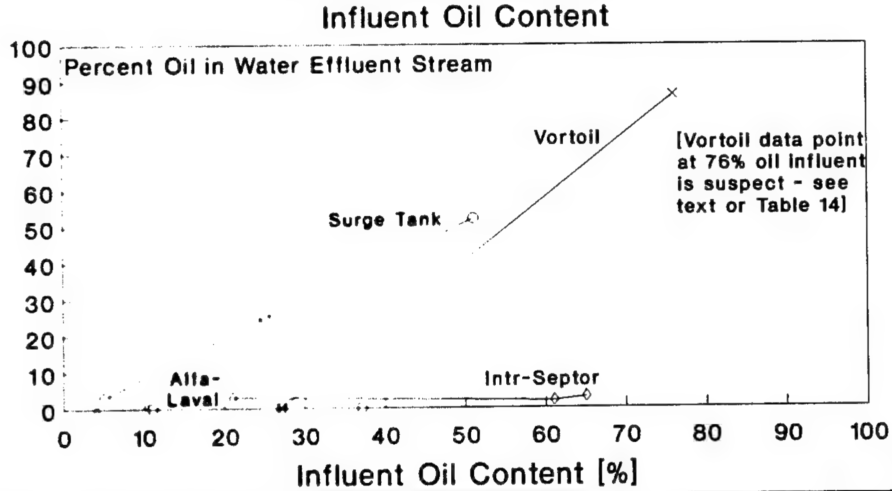


Figure 147:
Separator Performance Comparison: Crude Oil Test Series
Oil Content of Water Effluent Stream vs.
Influent Oil Content

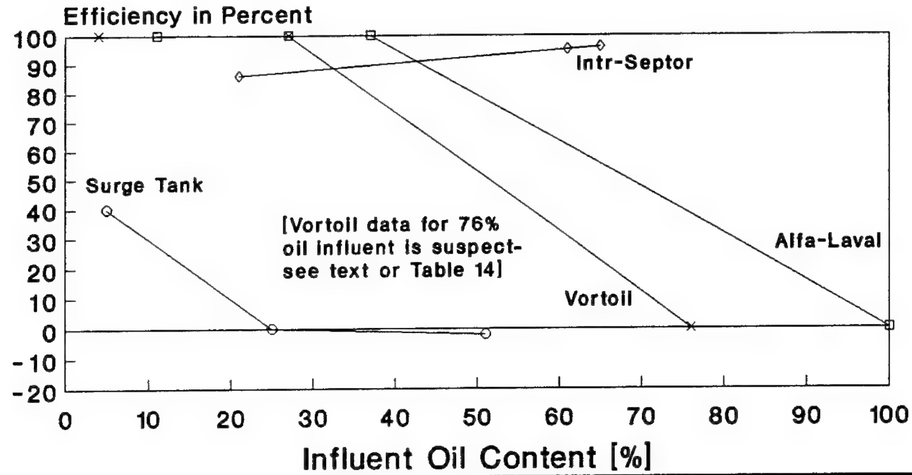


Average Influent Properties:

(All viscosity measurements taken at shear rate = 10 sec⁻¹)	Alfa-Laval	Surge Tank	Vortoil	Intr-Septor
	59 gpm	249 gpm	233 gpm	124 gpm
	210 cP @ 18 °C	333 cP @ 21 °C	883 cP @ 18 °C	1242 cP @ 17 °C
	Diff. SG = 0.119	Diff. SG = 0.132	Diff. SG = 0.108	Diff. SG = 0.104

Figure 148:

Separator Performance Comparison: Crude Oil Test Series
Hydrocarbon Removal Efficiency vs. Influent Oil Content



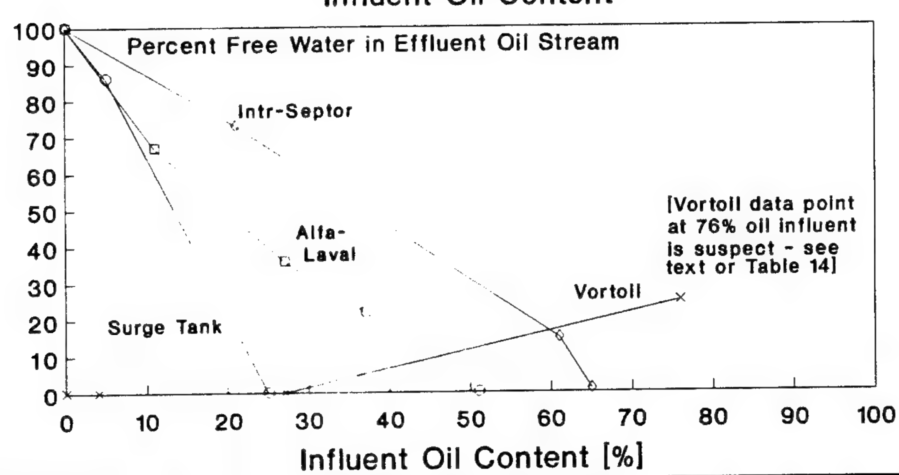
Average Influent Properties:

(All viscosity measurements taken at shear rate = 10 sec^{-1})

Alfa-Laval	Surge Tank	Vortoil	Intr-Septor
59 gpm	249 gpm	233 gpm	124 gpm
210 cP @ 18° C	333 cP @ 21° C	883 cP @ 18° C	1242 cP @ 17° C
Diff. SG = 0.119	Diff. SG = 0.132	Diff. SG = 0.108	Diff. SG = 0.104

Figure 149:

Separator Performance Comparison: Crude Oil Test Series
Free Water in Effluent Oil Stream vs.
Influent Oil Content



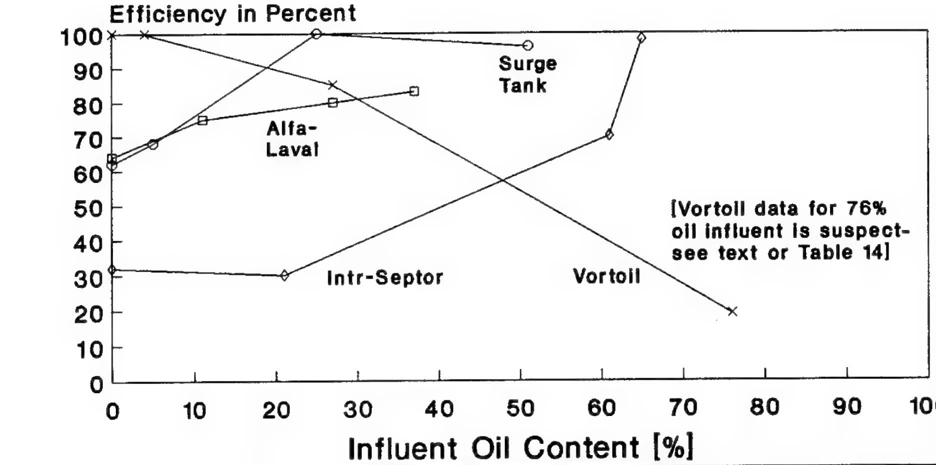
Average Influent Properties:

(All viscosity measurements taken at shear rate = 10 sec^{-1})

Alfa-Laval	Surge Tank	Vortoil	Intr-Septor
59 gpm	249 gpm	233 gpm	124 gpm
210 cP @ 18° C	333 cP @ 21° C	883 cP @ 18° C	1242 cP @ 17° C
Diff. SG = 0.119	Diff. SG = 0.132	Diff. SG = 0.108	Diff SG = 0.104

Figure 150:

Separator Performance Comparison: Crude Oil Test Series Water Removal Efficiency vs. Influent Oil Content



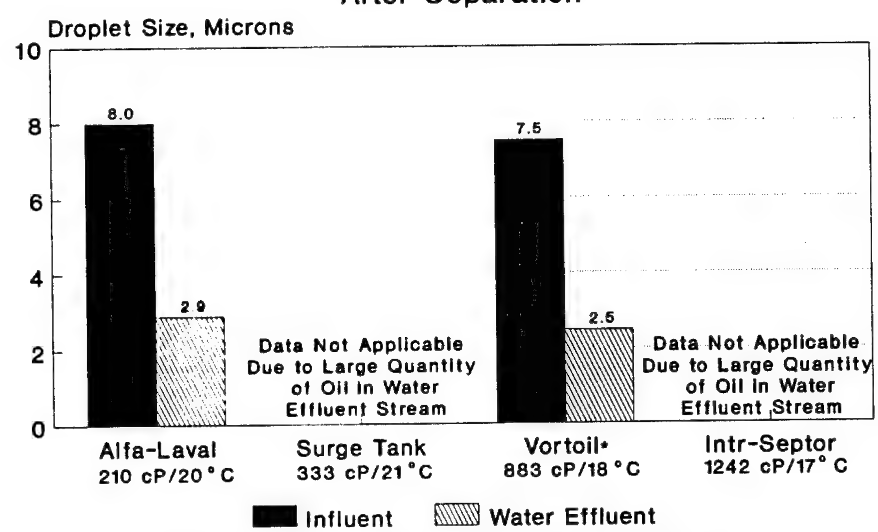
Average Influent Properties:

(All viscosity measurements taken at shear rate = 10 sec^{-1})

Alfa-Laval	Surge Tank	Vortoil	Intr-Septor
59 gpm	249 gpm	233 gpm	124 gpm
2210 cP @ 18 °C	333 cP @ 21 °C	883 cP @ 18 °C	1242 cP @ 17 °C
Diff. SG = 0.119	Diff. SG = 0.132	Diff. SG = 0.108	Diff. SG = 0.104

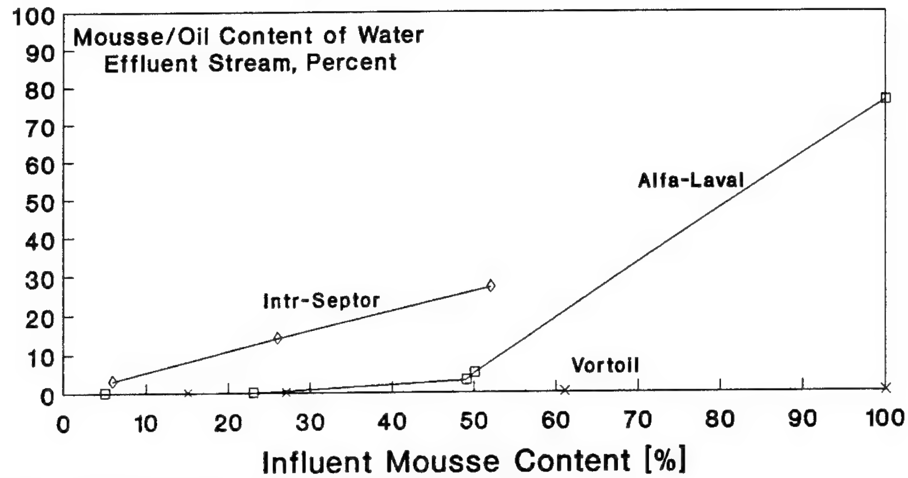
Figure 151:

Separator Performance Comparison: Crude Oil Test Series Change in Mean Oil Droplet Size After Separation



* Does not include data from tests where oil content of water effluent was large and not dispersed.
All viscosity measurements taken at shear rate = 10 sec^{-1}

Figure 152:
Separator Performance Comparison: Mousse Test Series
Mousse/Oil Content of Water Effluent vs.
Influent Mousse Content

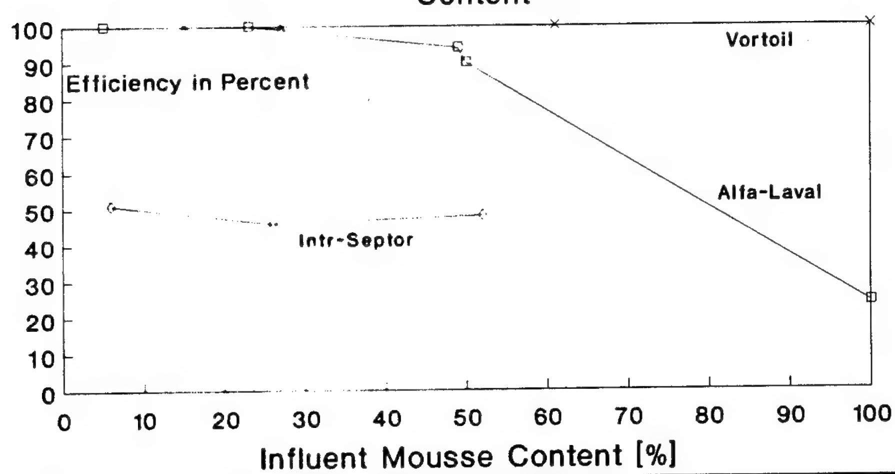


Average Infuent Properties:

(All viscosity measurements taken at shear rate = 10 sec^{-1})

Alfa-Laval	Vortoil	Intr-Septor
63 gpm	256 gpm	143 gpm
4163 cP @ 20°C	25932 cP @ 14°C	26300 cP @ 16°C
Diff. SG = 0.083	Diff. SG = 0.099	Diff SG = 0.101

Figure 153:
Separator Performance Comparison: Mousse Test Series
Hydrocarbon Removal Efficiency vs. Influent Mousse
Content



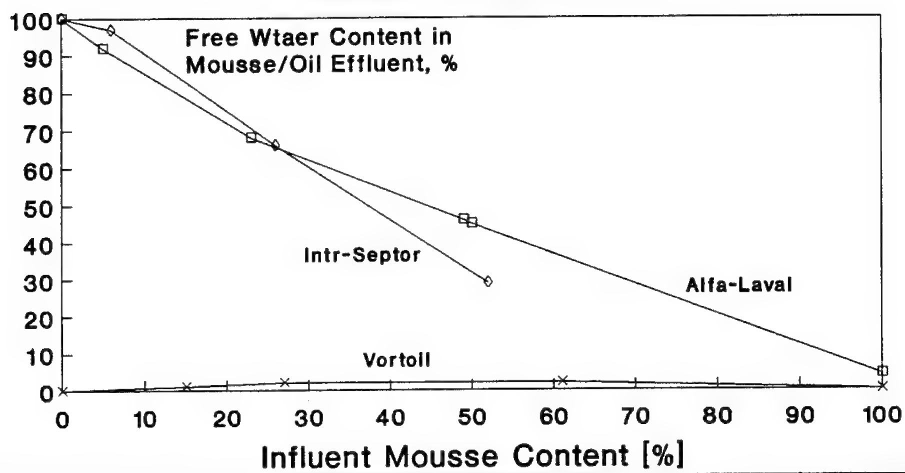
Average Inlfuent Properties:

(All viscosity measurements taken at shear rate = 10 sec^{-1})

Alfa-Laval	Vortoil	Intr-Septor
63 gpm	256 gpm	143 gpm
4163 cP @ 20°C	25932 cP @ 14°C	26300 cP @ 16°C
Diff. SG = 0.083	Diff. SG = 0.099	Diff. SG = 0.101

Figure 154:

Separator Performance Comparison: Mousse Test Series
Free Water Content of Mousse/Oil Effluent vs.
Influent Mousse Content



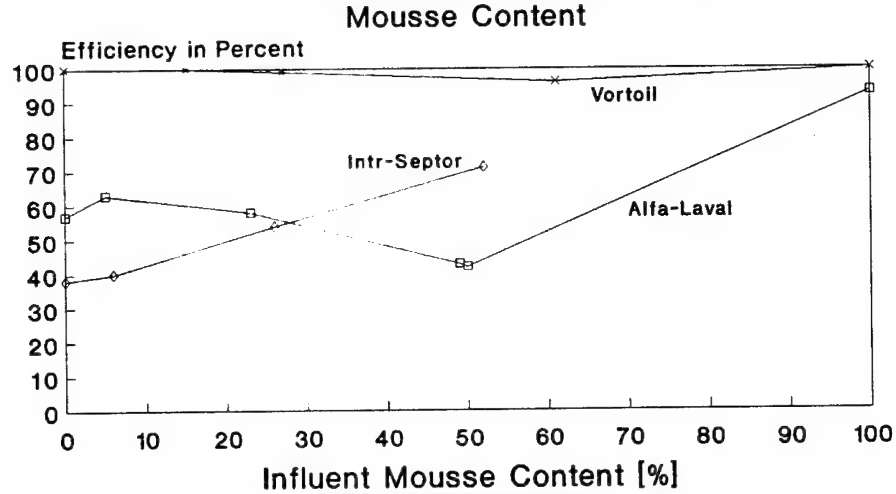
Average Influent Properties

(All viscosity measurements taken at shear rate = 10 sec^{-1})

Alfa-Laval	Vortoil	Intr-Septor
63 gpm	256 gpm	143 gpm
4163 cP @ 20 °C	25932 cP @ 14 °C	26300 cP @ 16 °C
Diff. SG = 0.083	Diff. SG = 0.099	Diff. SG = 0.101

Figure 155:

Separator Performance Comparison: Mousse Test Series
Water Removal Efficiency vs. Influent
Mousse Content



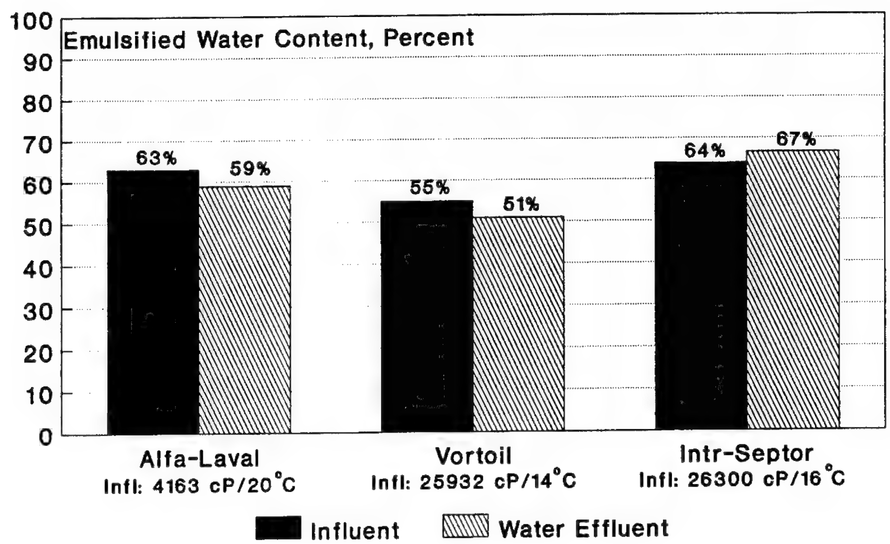
Average Influent Properties

(All viscosity measurements taken at shear rate = 10 sec^{-1})

Alfa-Laval	Vortoil	Intr-Septor
63 gpm	256 gpm	143 gpm
4163 cP @ 20 °C	25932 cP @ 14 °C	26300 cP @ 16 °C
Diff. SG = 0.083	Diff. SG = 0.099	Diff. SG = 0.101

Figure 156:

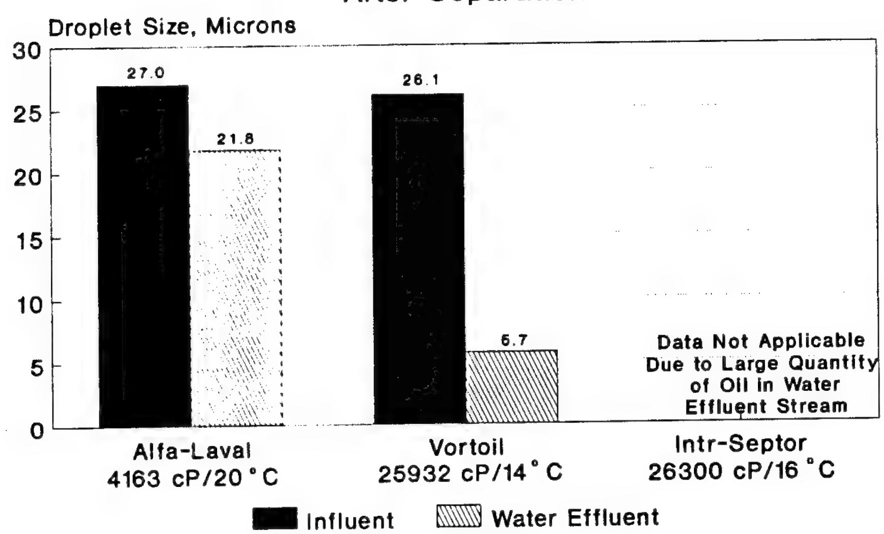
Separator Performance Comparison: Mousse Test Series
Change in Emulsified Water Content of Mousse Before and After Separation



All viscosity measurements taken at shear rate = 10 sec^{-1}

Figure 157:

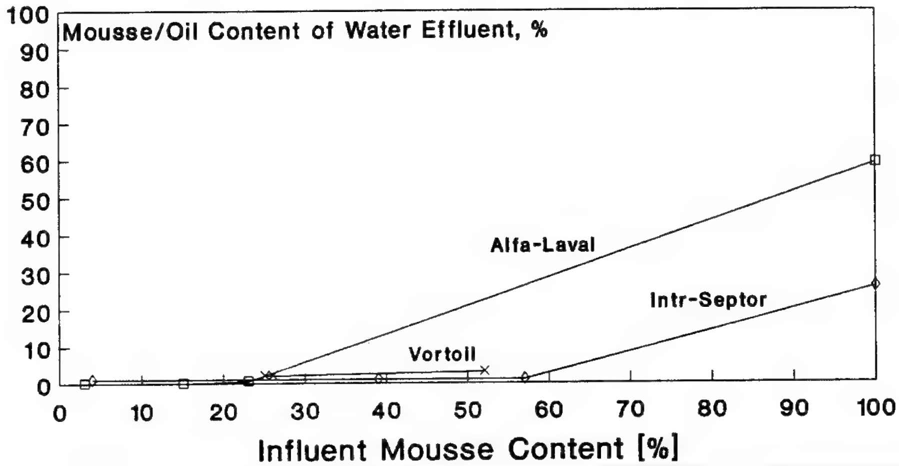
Separator Performance Comparison: Mousse Test Series
Change in Mean Oil Droplet Size After Separation



All viscosity measurements taken at shear rate = 10 sec^{-1}

Figure 158:

Separator Performance Comparison: Mousse With Emulsion Breaker Test Series: Moussse/Oil Content of Water Effluent vs. Influent Mousse Content

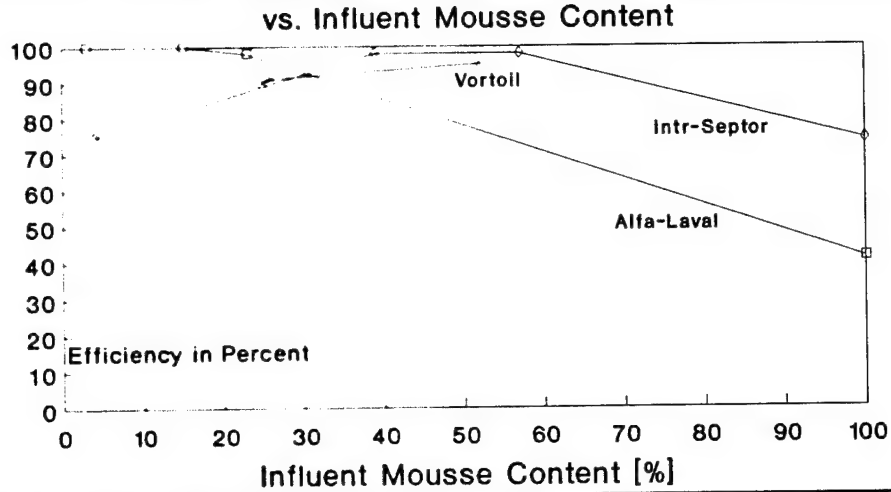


Average Influent Properties After Emulsion Breaker:

(All viscosity measurements taken at shear rate = 10 sec^{-1})	Alfa-Laval	Vortoil	Intr-Septor
	69 gpm	272 gpm	143 gpm
	278 cP @ 18 °C	16800 cP @ 13 °C	9293 cP @ 16 °C
	Diff. SG = 0.124	Diff. SG = 0.099	Diff. SG = 0.101

Figure 159:

Separator Performance Comparison: Mousse With Emulsion Breaker Test Series: Hydrocarbon Removal Efficiency vs. Influent Mousse Content

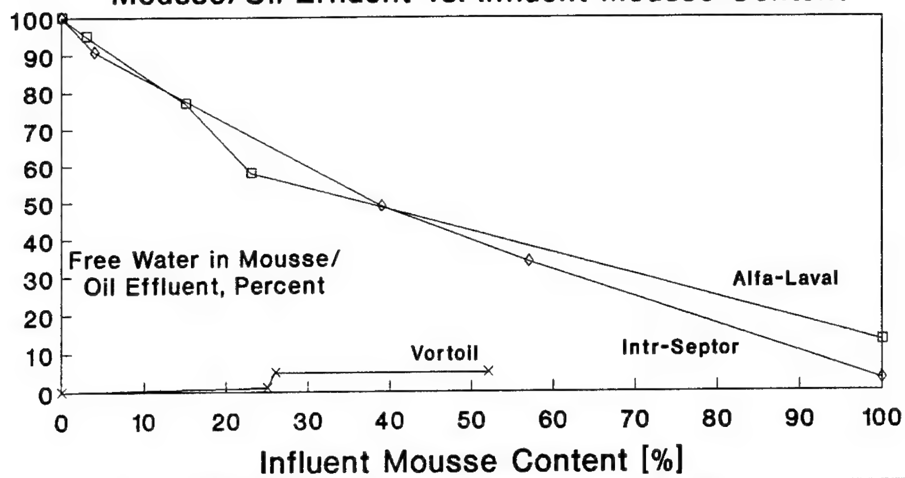


Average Influent Properties After Emulsion Breaker:

(All viscosity measurements taken at shear rate = 10 sec^{-1})	Alfa-Laval	Vortoil	Intr-Septor
	69 gpm	272 gpm	143 gpm
	278 cP @ 18 °C	16800 cP @ 13 °C	9293 cP @ 16° C
	Diff. SG = 0.124	Diff. SG = 0.099	Diff. SG = 0.101

Figure 160:

Separator Performance Comparison: Mousse With Emulsion Breaker Test Series: Free Water Content of Mousse/Oil Effluent vs. Influent Mousse Content



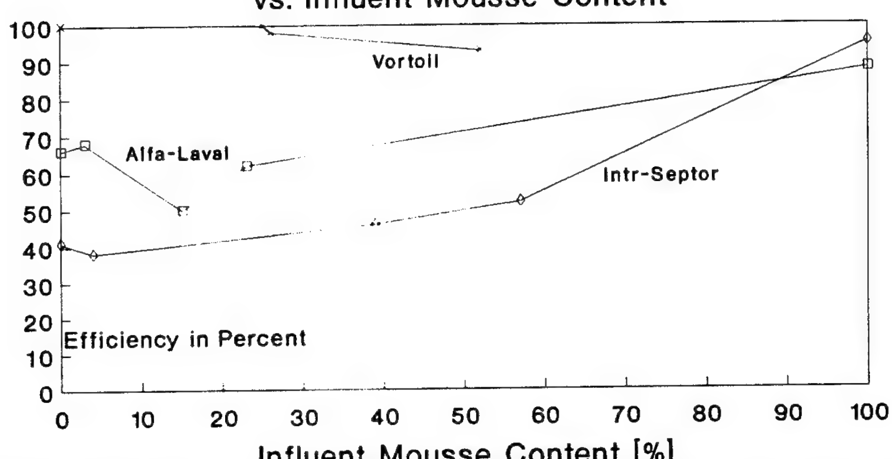
Average Influent Properties After Emulsion Breaker:

(All viscosity measurements taken at shear rate = 10 sec^{-1})

Alfa-Laval	Vortoil	Intr-Septor
69 gpm	272 gpm	143 gpm
278 cP @ 18 °C	16800 cP @ 13 °C	9293 cP @ 16 °C
Diff. SG = 0.124	Diff. SG = 0.099	Diff. SG = 0.101

Figure 161:

Separator Performance Comparison: Mousse With Emulsion Breaker Test Series: Water Removal Efficiency vs. Influent Mousse Content



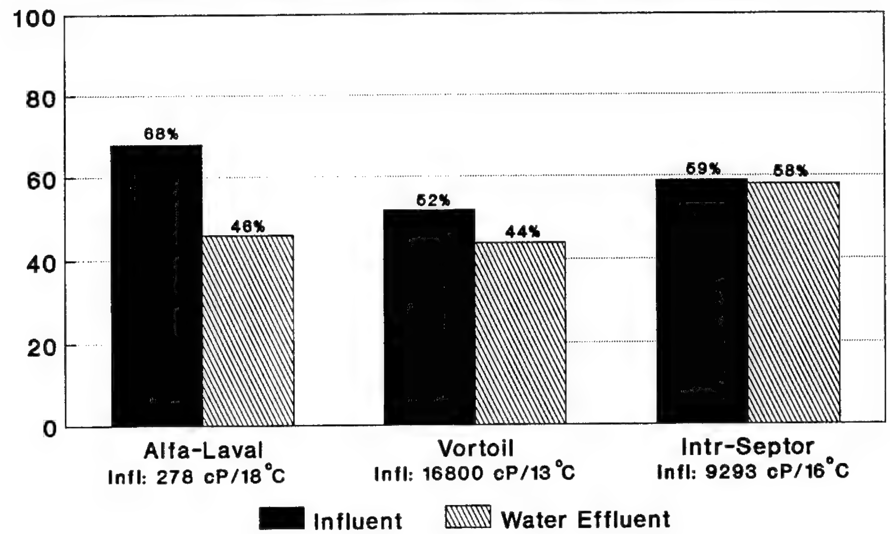
Aveage Influent Properties After Emulsion Breaker:

(All viscosity measurements taken at shear rate = 10 sec^{-1})

Alfa-Laval	Vortoil	Intr-Septor
69 gpm	272 gpm	143 gpm
278 cP @ 18 °C	16800 cP @ 13 °C	9293 cP @ 16 °C
Diff. SG = 0.124	Diff. SG = 0.099	Diff. SG = 0.101

Figure 162:

Separator Performance Comparison: Mousse With Emulsion Breaker Test Series: Change in Emulsified Water Content Before and After Separation



All viscosity measurements taken at shear rate = 10 sec^{-1}

Figure 163:

Separator Performance Comparison: Mousse With Emulsion Breaker Test Series Impact of Emulsion Breaker Exxon Breaxit 7877 on Viscosity

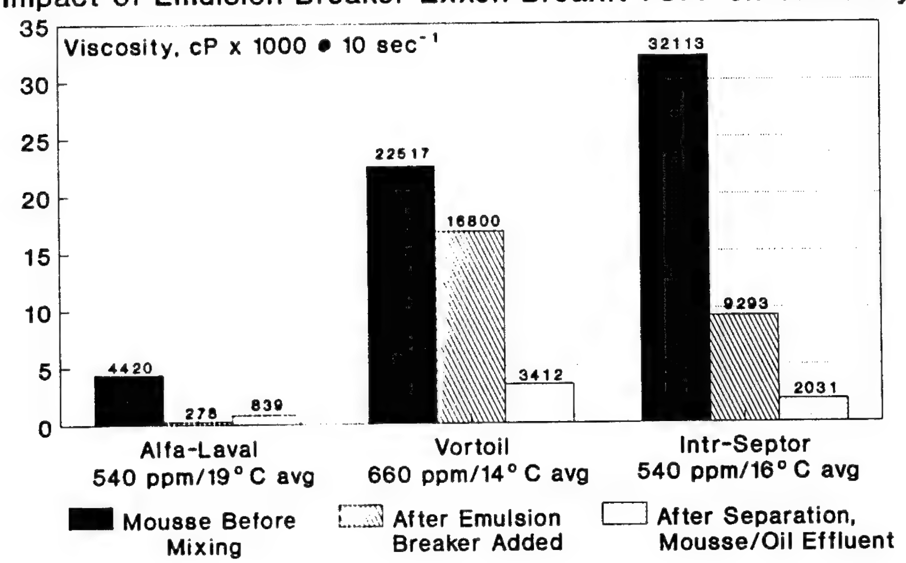
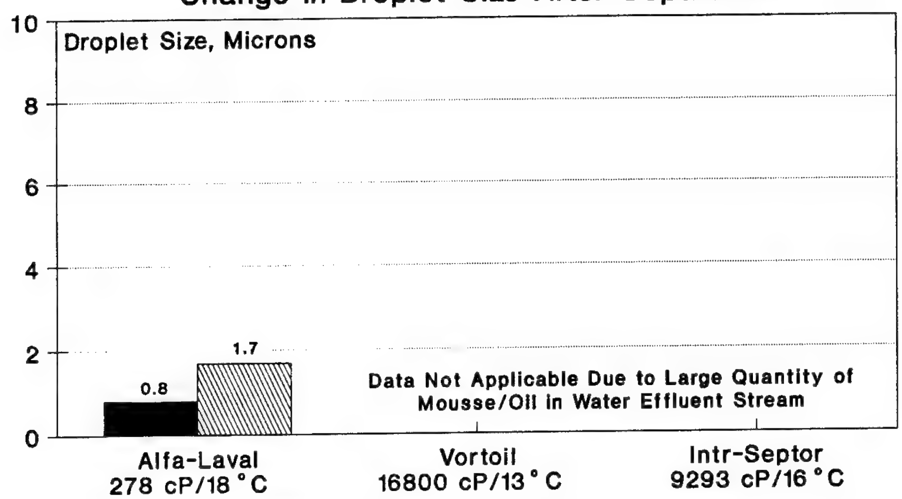


Figure 164:

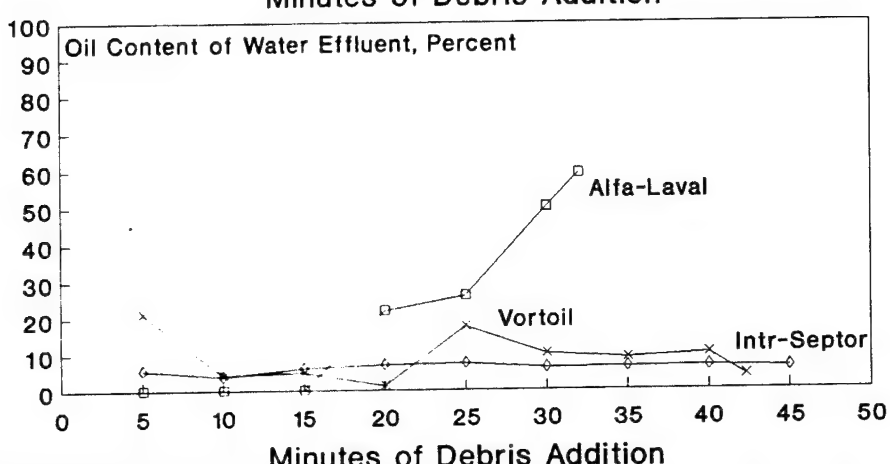
Separator Performance Comparison: Mousse With Emulsion Breaker Test Series: Change in Droplet Size After Separation



All viscosity measurements taken at shear rate = 10 sec^{-1}
Influent properties shown include impact of emulsion breaker

Figure 165:

Separator Performance Comparison: Debris Test Series Oil Content of Water Effluent Stream vs. Minutes of Debris Addition



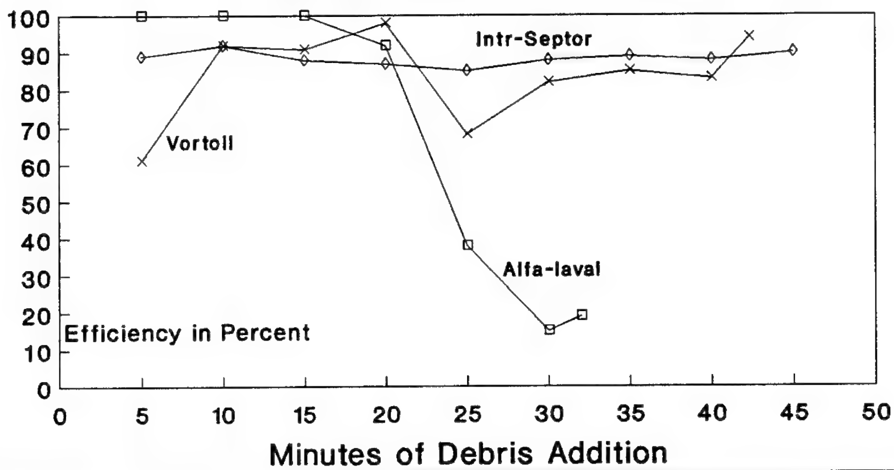
Average Influent Properties:

(All viscosity measurements taken at shear rate = 10 sec^{-1})

Alfa-Laval	Vortoil	Intr-Septor
59 gpm, 47% Oil	224 gpm, 56% Oil	113 gpm, 51% Oil
536 cP @ 20 °C	1110 cP @ 18 °C	514 cP @ 20 °C
Diff. SG = 0.149	Diff. SG = 0.103	Diff. SG = 0.102

Figure 166:

Separator Performance Comparison: Debris Test Series
Hydrocarbon Removal Efficiency vs.
Minutes of Debris Addition

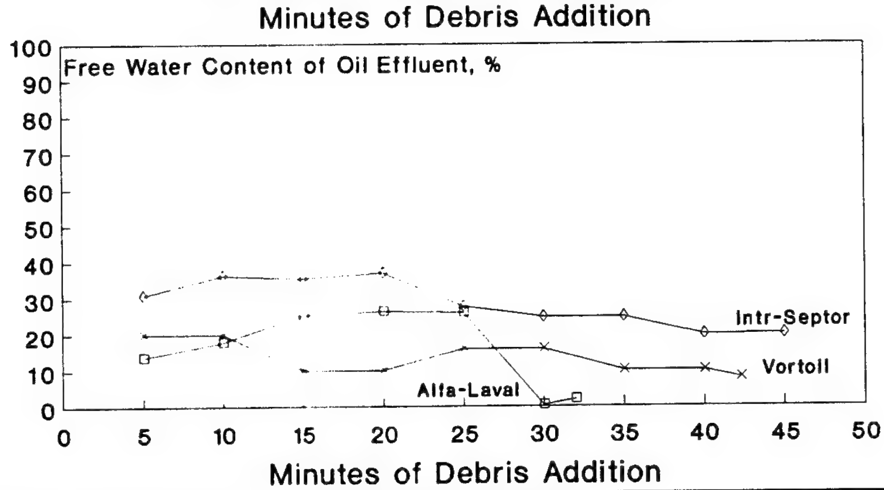


Average Influent Properties:

(All viscosity measurements taken at shear rate = 10 sec^{-1})	Alfa-Laval	Vortoil	Intr-Septor
	59 gpm, 47% Oil	224 gpm, 56% Oil	113 gpm, 51% Oil
	536 cP @ 20 °C	1110 cP @ 18 °C	514 cP @ 20 °C
	Diff. SG = 0.149	Diff. SG = 0.103	Diff. SG = 0.102

Figure 167:

Separator Performance Comparison: Debris Test Series
Free Water Content of Oil Effluent vs.
Minutes of Debris Addition

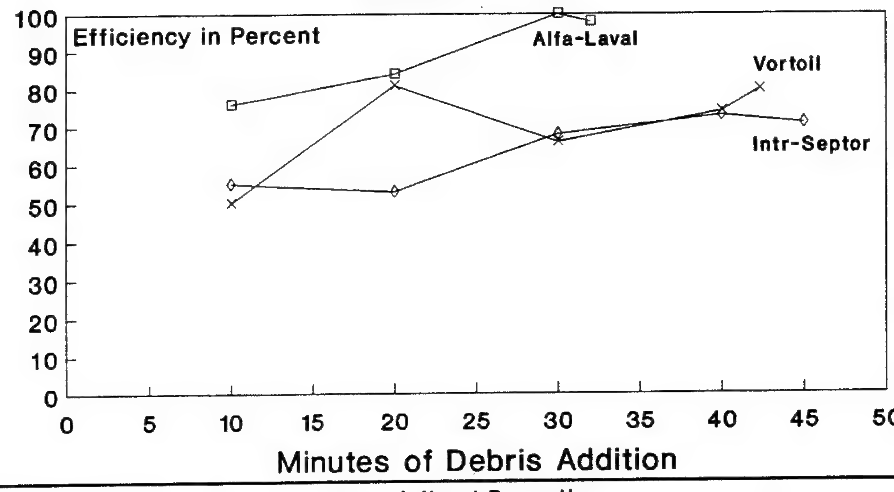


Average Influent Properties:

(All viscosity measurements taken at shear rate = 10 sec^{-1})	Alfa-Laval	Vortoil	Intr-Septor
	59 gpm, 47% Oil	224 gpm, 56% Oil	113 gpm, 51% Oil
	536 cP @ 20 °C	1110 cP @ 18 °C	514 cP @ 20 °C
	Diff. SG = 0.149	Diff. SG = 0.103	Diff. SG = 0.102

Figure 168:

Separator Performance Comparison: Debris Test Series Water Removal Efficiency vs. Minutes of Debris Addition

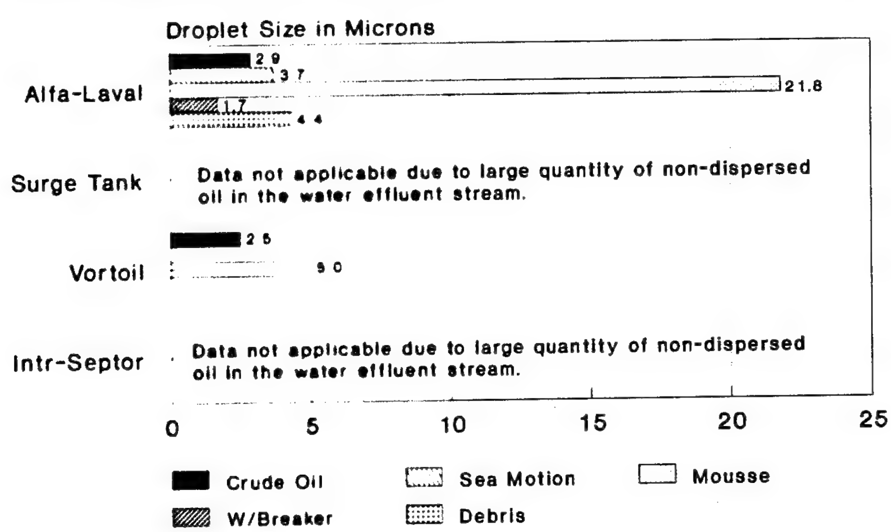


Avergae Influent Properties:

(All viscosity measurements taken at shear rate = 10 sec^{-1})	Alfa-Laval	Vortoil	Intr-Septor
	59 gpm, 47% Oil	224 gpm, 56% Oil	113 gpm, 51% Oil
	536 cP @ 20 °C	1110 cP @ 18 °C	514 cP @ 20 °C
	Diff. SG = 0.149	Diff. SG = 0.103	Diff. SG = 0.102

Figure 169:

Separator Performance Comparison: Mean Oil Droplet Size Remaining in Water Effluent Stream After Separation



Data shown only for those tests where the oil content of the water effluent stream was dispersed.

TABLE 1:
Oil/Water Separator Test Petroleum Products: Target and Actual Properties

Product:	Property:	Target Value:	Typical Actual Value:
Crude Oil	Viscosity:	1500 cP	500 - 1300 cP @ 16°C
	Specific Gravity:	0.90 - 0.98 (low end)	0.92
	Interfacial Tension:	N/A	3.9 - 43.5 dynes/cm (avg 25.0 dynes/cm)
Water-in Oil Emulsion ("Mousse")	Viscosity:	50,000 - 60,000 cP	2,000 - 36,000 cP (avg 20,000 cP @ 18°C)
	Specific Gravity:	0.90 - 0.98 (high end)	0.93 - 0.98
	Entrained Water Volume:	60% - 70%	55% - 70%
	Interfacial Tension:	N/A	25.2 - 43.5 dynes/cm (avg 34.5 dynes/cm)

Note: All viscosity measurements taken at shear rate = 10 sec^{-1}.

TABLE 2:
ALFA-LAVAL OFPX 413 SYSTEM AND LOGISTICS DATA

Separator Weight (lbs) (see notes 1 and 2)	13800
Power System Weight (lbs) (see note 3)	3000
Total System Weight (lbs)	**16800**
Separator Capacity (gpm) (see note 4)	**65**
System Weight to Capacity Ratio (lbs/gpm)	**258**
Separator Length (ft) (see note 5)	10.0
Separator Width (ft) (see note 5)	8.0
Separator Height (ft) (see notes 2 and 5)	14.0
Separator Footprint Area (sq ft)	**80.0**

NOTES:

1. Includes main unit (11300 lbs), base unit (1300 lbs), and pump unit (1200 lbs). See note 5 regarding base unit.

2. The base unit for this system was modified by reducing the height (and therefore volume) to enable us to safely place the unit on the tilt table. The weight shown for the separator system was measured with the reduced base unit.

3. Weight of ESSM 30 Kw generator.

4. 65 gpm is the manufacturer's rated capacity. The highest sustained rate observed during the tests was 73 gpm with an influent oil ratio of 17% and a viscosity of 890 Cp. Using 73 gpm, this unit's capacity to weight ratio is 230, but this does not take into account the smaller base unit used for these tests (see note 5).

5. The unit was not measured at the test site. The data here were provided by the manufacturer.

TABLE 3:
ALFA-LAVAL OFPX 413 CRUDE OIL TEST SERIES
TEST RESULTS SUMMARY

Test Date: 16 November 1992

Test #	INFLUENT PROPERTIES						OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Oil (a)	SG_{oil}/SG_{w}	Oil Visc (cP) (1),(b)	Emuls Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	% Oil	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	67	9 ppm	N/A	N/A	N/A	82.9	24	36	1[c]	N/A	43	64	6 ppm	154.6	64	N/A
2	67	11	(d)	(d)	11.8	10.1	22	33	33	10.0	45	67	0	0.9	75	100
3	63	27	0.095	442	1.5	6.6	26	41	64	6.2	37	59	4 ppm	2.1	80	100
4	56	37	0.143	169	1.2	7.3	27	48	78	3.8	30	52	442 ppm	5.6	83	100
5	45	100	N/A	18	1.9	N/A	18	41	100	1.0	27	59	100	N/A	N/A	0
6	54	87 ppm	N/A	N/A	N/A	11.1	20	36	1[c]	N/A	35	64	218 ppm	10.6	63	N/A

(1) In oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency = (volume of water discharged through water effluent/volume of water in influent) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent oil content [ppm or %] - water effluent stream oil content [ppm or %])/influent oil content [ppm or %]) X 100.

Notes on Data (correspond to superscripts in table):

(a) Calculated from mass balance analysis for tests #2 through #5.
(b) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 18° C.
(c) Oil content shown here is assumed to be from residual oil remaining in the lines after the previous test series.
(d) Insufficient sample available for analysis.

(continued on next page)

TABLE 3: ALFA-LAVAL OFPX 413 CRUDE OIL TEST SERIES TEST RESULTS SUMMARY (continued)

Comments and Observations:

1. The reduced capacity tests originally included in the plans for this series were omitted due to the already low total flow rate of the separator. The original plans called for 50% and 25% capacity tests at 5% influent oil, which could not be conducted due to the extremely low influent oil rates (less than 2 gpm) that would have had to be sustained. The lowest sustainable influent oil rate achieved during the tests was approximately 6 gpm.

TABLE 4:
ALFA-LAVAL OFPX 413 SEA MOTION TEST SERIES
TEST RESULTS SUMMARY

Test Date: 17 November 1992

Test #	INFLUENT PROPERTIES						OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Oil (a)	SG / SG	Oil Visc (cP) (1),(b)	Emuls. Water Vol (%) (1)	Mean Droplet Size (mic)	Flow Rate (gpm)	% of Total Flow	% Oil	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	73	23 ppm	N/A	N/A	N/A	2.7	28	38	0	N/A	46	62	100 ppm	3.1	62	N/A
2	73	17	0.099	759	1.9	3.6	29	40	43	2.1	44	60	44 ppm	2.7	73	100
3	43	41	0.118	46	1.8	5.0	25	58	70	2.1	18	42	8 ppm	7.2	71	100
4	45	61	0.136	15	2.1	5.8	27	60	100	25.7	18	40	95 ppm	1.3	100	100
5	52(c)	100	N/A	62	0.4	N/A	48	91(c)	100	2.5	5(c)	9(c)	100	N/A	N/A	0
6	(d)	189 ppm	N/A	N/A	N/A	21.3	21	(d)	1(c)	N/A	(d)	(d)	0	14.0	(d)	N/A

(1) In oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency = (volume of water discharged through water effluent/volume of water in influent) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent oil content [ppm or %] - water effluent oil stream content [ppm or %])/influent oil content [ppm or %]) X 100.

Notes on Data (correspond to superscripts in table):

(a) Calculated from mass balance analysis for tests #2 through #5.
(b) Viscosity measurements taken at shear rate = 25 sec^{-1}, at an average temperature of 20° C. For all other test series, viscosity data was recorded at shear rate 10 sec^{-1}. This is the only test series where viscosity data at shear rate = 10 sec^{-1} is not available.

(continued on next page)

TABLE 4: ALFA-LAVAL OFPX 413 SEA MOTION TEST SERIES TEST RESULTS SUMMARY (continued)

Notes on Data (correspond to superscripts in table, continued):

(c) Effluent water stream flow rate data is suspect for this test. The actual rate may be slightly higher than shown.
(d) No water effluent flow rate data was obtained during this test.
(e) Oil content shown here is assumed to be from residual oil remaining in the lines after the previous test.

Comments and Observations:

1. Swing table motion for this test series was ± 15 deg. The period at the start of the test was 6.9 seconds, gradually decreasing to 6.5 seconds by the end of the tests. The reason for the slight increase in speed was unknown.

2. Target influent oil ratios for the six tests of this series were 0%, 5%, 25%, 50%, 100% and 0% respectively. Poor ability to monitor and hence control influent flow rates and oil/water ratios resulted in the higher actual oil ratios. Because the effluent stream oil/water ratio data is more reliable in general, it was used for this series test to derive the influent oil/water ratios shown in the table.

3. A gradual decrease in the viscosity and density of the oil product as it was pumped from the test site oil supply tank was observed during this test. It was later learned that the oil in the refinery tank, from which the test oil was supplied, was thinned with lighter oils as tank level dropped toward empty. At the test site, oil was pumped from the bottom of the supply tank, drawing off the heavier fluids first, and successively lighter fluids as the test progressed. The impact can be seen in both the viscosity and difference in specific gravities data in the table.

4. During test #5 (100% oil), two water effluent stream samples contained significant amounts of water (40% and 99%). It is assumed that this was the result of pockets of water remaining in the lines before the test was started. These two data points were eliminated before averaging the water effluent oil content data for this test.

TABLE 5:
ALFA-LAVAL OFPX 413 MOUSSE TEST SERIES
TEST RESULTS SUMMARY

Test Date: 18 November 1992

Test #	INFLUENT PROPERTIES						MOUSSE/OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Mousse	SG / SG	Mousse Visc (cP) (1),(a)	Emuls. Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	Mousse/ Oil Content (%)	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Mousse/ Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	58[b]	0	N/A	N/A	N/A	36.3	25	43[b]	1[c]	N/A	33[b]	57[b]	10 ppm	27.2	57[b]	N/A
2	68[b]	5	(d)	(d)	(d)	37.5	26	39[b]	8	(d)	42[b]	61[b]	3 ppm	27.3	63[b]	100
3	72	23	0.110	4320	61.6	16.5	37	51	32	55.4	35	49	5 ppm	15.9	58	100
4	67	49	0.066	4060	63.2	21.7	50	74	54	65.5	18	26	3	N/A	43	94
4a	57	50	0.074	3760	61.1	9.6	43	75	55	57.9	14	25	5	N/A	42	90
5	49	100	N/A	4510	66.6	N/A	16	33	96	57.5	33	67	76	N/A	93	24
6	68	29 ppm	N/A	N/A	N/A	27.4	21	31	1[c]	N/A	47	69	63 ppm	17.0	68	N/A

(1) In mousse/oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency for Mousse Tests = (volume of water discharged through water effluent/total volume of free water in both effluents) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent mousse content [ppm or %] - water effluent stream mousse/oil content [ppm or %])/influent mousse content [ppm or %]) X 100.

Notes on Data (correspond to superscripts in table):

(a) Viscosity measurements taken at shear rate = 10 sec^{-1}; at an average temperature of 20° C.
(b) Water effluent rate data for these two tests is suspect. Actual rates for water effluent flow are likely to be slightly higher than shown.

(continued on next page)

TABLE 5: ALFA-LAVAL OFPX 413 MOUSSE TEST SERIES TEST RESULTS SUMMARY (continued)

Notes on Data (correspond to superscripts in table, continued):

(c) Mousse/oil content shown here is assumed to be from residual oil remaining in the lines after the previous test.
(d) Insufficient sample available for analysis.

Comments and Observations:

1. Test #4 was repeated during this test because it was believed that the first test #4 had been conducted at a flow rate over the separator's stated capacity of 65 gpm.

2. Although the data indicates that emulsion was "broken" during this test series, no visual indication of the demulsification (such as three phase flow - oil, water and mousse) was noted during the test.

3. Mousse property data before and after separation is shown in Table 6 on the following page.

TABLE 6:
ALFA-LAVAL OFPX 413 MOUSSE TEST SERIES
MOUSSE PROPERTIES DURING TEST

Test Date: 18 November 1992

Test #	Percent Mousse in Influent	EMULSIFIED WATER VOLUME (%)				VISCOSITY (cP) (at Shear Rate = 10 sec^{-1})				SPECIFIC GRAVITY			
		Mousse Supply Line	Influent Mixture (Mousse/Oil Portion)	Mousse/Oil Effluent Stream (Mousse/Oil Portion)	Change from Influent to Effluent	Mousse Supply Line @ 22° C	Influent Mixture (Mousse/Oil Portion) @ 20° C	Mousse/Oil Effluent Stream (Mousse/Oil Portion) @ 21 ° C	Change from Influent to Effluent	Mousse Supply Line	Influent Mixture (Mousse/Oil Portion)	Mousse/Oil Effluent Stream (Mousse/Oil Portion)	Change from Influent to Effluent
1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	5	63.5	(a)	(a)	(a)	3350	(a)	(a)	(a)	0.960	(a)	(a)	(a)
3	23	62.2	61.6	55.4	- 6.2	2885	5080	3855	- 465	0.961	0.914	0.885	- 0.029
4	49	60.3	63.2	65.5	+ 2.3	3480	4060	3625	- 435	0.960	0.957	0.903	- 0.054
4a	50	63.6	61.1	57.9	- 3.2	3625	3760	3420	- 340	0.909	0.949	0.908	- 0.041
5	100	67.3	66.6	57.5	- 9.1	4050	4510	4420	- 90	0.936	0.959	0.913	- 0.046
6	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

NOTES:

(a) Insufficient sample available for analysis.

TABLE 7:
ALFA-LAVAL OFPX 413 MOUSSE WITH EMULSION BREAKER TEST SERIES TEST RESULTS SUMMARY

Test Date: 19 November 1992

Test #	INFLUENT PROPERTIES						MOUSSE/OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Mousse (a)	SG_{water} / SG_{mousse}	Mousse Visc (cP) (1) (b)	Emuls. Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	Mousse/ Oil Content (%)	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Mousse/Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	65	8 ppm	N/A	N/A	N/A	0.7	22	34	0	N/A	43	66	84 ppm	0.7	66	N/A
2	66	3	(c)	(c)	91.0	1.3	22	34	5	86.3	44	66	424 ppm	1.0	68	100
3	57	15	0.120	342	54.4	0.6	32	56	23	45.3	25	44	7 ppm	1.4	50	100
4	78	23	0.118	88	47.6	0.5	40	52	42	49.4	37	48	0.4	2.6	62	98
5	75	100	0.133(d)	403	30.6	31.1	21	29	87	2.1	54	71	59	N/A	88	41

(1) In mousse/oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency for Mousse Tests = (volume of water discharged through water effluent/total volume of free water in both effluents) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent mousse/oil content [ppm or %] - water effluent stream mousse/oil content [ppm or %])/influent mousse/oil content [ppm or %]) X 100.

Notes on Data (correspond to superscripts in table):

(a) Calculated from mass balance analysis for tests #2 through #4.
(b) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average temperature of 18° C.
(c) Insufficient sample available for analysis.
(d) Enough separation had occurred between injection of emulsion and the influent sampling point to obtain density data on the free water portion for one of the two lab samples taken at the influent sampling station. The sample

(continued on next page)

TABLE 7:
ALFA-LAVAL OFPX 413 MOUSSE WITH EMULSION BREAKER TEST SERIES TEST RESULTS SUMMARY (continued)

Notes on Data (correspond to superscripts in table, continued):

was approximately 10% free water and 90% oil/mousse. Because lab samples were allowed to settle for a full five minutes before analysis, and because this was noted in only one of the two samples, this "pre-separator" separation was not taken into consideration in the analysis of the data.

Comments and Observations:

1. The EXXON emulsion breaker Breaxit 7877 was added at a rate of 140 ml/min, corresponding to a dosage of 540 ppm of the total flow for each test.

2. One water effluent sample during test #4 contained 3% oil, all others were clean. Ommitting this one sample from the water purification efficiency calculations produces 100% purification efficiency for this test.

3. During test #5, the Alfa-Laval system feed pump began to slow about half way through the test. A rise in the level of the influent feed tank (required for testing the Alfa-Laval system) was observed, corresponding to a rate of approximately 14 gpm. The flow rate in the table is an average over each ten minute test period, derived from the effluent stream volumes.

4. Mousse property data before the addition of the emulsion breaker, and before and after separation, is shown in the table on the following page.

TABLE 8:
ALFA-LAVAL OFPX 413 MOUSSE WITH EMULSION BREAKER TEST SERIES MOUSSE PROPERTIES DURING TEST

Test Date: 19 November 1992

Test #	Percent Mousse in Influent	EMULSIFIED WATER VOLUME (%)				VISCOSITY (cP) (at Shear Rate = 10 sec^{-1})				SPECIFIC GRAVITY			
		Mousse Supply Line	Influent Mixture (Mousse Oil Portion) (a)	Mousse Oil Effluent Stream (Mousse Oil Portion)	Change from Influent to Effluent	Mousse Supply Line @ 20° C	Influent Mixture (Mousse/Oil Portion) (a) @ 18° C	Mousse/Oil Effluent Stream (Mousse/Oil Portion) @ 19 ° C	Change from Influent to Effluent	Mousse Supply Line	Influent Mixture (Mousse/Oil Portion) (a)	Mousse/Oil Effluent Stream (Mousse/Oil Portion)	Change from Influent to Effluent
1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	3	68.3	91.0	86.3	- 4.7	5760	(b)	(b)	(b)	0.947	(b)	(b)	(b)
3	15	76.4	54.4	45.3	- 9.1	5995	342	1250	+ 908	0.957	0.903	0.790	- 0.113
4	23	74.9	47.6	49.4	+ 1.8	3875	88	786	+ 698	0.954	0.905	0.917	- 0.012
5	100	50.0	30.6	2.1	- 28.5	2050	403	480	+ 77	0.935	0.883	0.892	- 0.009

NOTES:

(a) Includes effect of emulsion breaker. Emulsion breaker added upstream of influent sampling station.
(b) Insufficient sample available for analysis.

TABLE 9:
ALFA-LAVAL OFPX 413 DEBRIS TEST SERIES
TEST RESULTS SUMMARY

Test Date: 21 November 1992

	INFLUENT PROPERTIES						OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
Test #	Flow Rate (gpm)	% Oil (a)	SG / SG_w	Oil Visc. (cP) (1),(b)	Emuls. Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	% Oil	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	71	506 ppm	N/A	N/A	N/A	5.2	22	31	(c)	N/A	49	69	1 ppm	13.6	69	N/A
2.1	60	56	0.159	522	2.6	0.5	40	66	84	3.8	20	34	7 ppm	7.2	76	100
2.2	68	33	0.152	543	2.7	0.5	29	43	74	2.9	39	57	1	1.6	84	96
2.3	58	47	0.137	542	2.9	4.0	10	18	99	2.7	47	82	36	N/A	100	24
2.4	10[d]	73	(e)	(e)	(e)	(e)	4	36	99	(e)	6	64	59	N/A	98	19
2.5	_	-	-			-	-	-	-	-	-	-	-	-	-	-
2 (avg)	59	47	0.149	536	2.7	1.7	25	43	86	3.1	33	57	15	N/A	91	68

(1) In oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency = (volume of water discharged through water effluent/volume of water in influent) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent oil content [ppm or %] - water effluent stream oil content [ppm or %])/influent oil content [ppm or %]) X 100

Notes on Data (correspond to superscripts in table):

(a) Influent oil ratio calculated from mass balance equations using the effluent stream data for this test.
(b) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an avergae temperature of 20° C.
(c) No data available, assumed to be 0%.

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TABLE 9: ALFA-LAVAL OFPX 413 DEBRIS TEST SERIES TEST RESULTS SUMMARY (continued)

Notes on Data (correspond to superscripts in table, continued):

(d) Test was aborted 2 minutes into this test period, low flow rate probably reflects shut down of Alfa-Laval effluent pumps. See comment #2 below.

(e) Test was aborted before a lab analysis sample could be collected for this test period.

Comments and Observations:

1. Debris was added at rate of 0.065 lbs per minute over the 32 minutes of testing in test #2. The debris mixture consisted of 10% by weight 1/4 inch wood shavings, 10% #10 mesh size sawdust, 40% #40 mesh size sawdust, and 40% #140 mesh size sawdust.

2. Alfa-Laval operator requested that the test be stopped immediately 32 minutes into test #2. The disk stack was becoming clogged and continuing the test could have resulted in damage to the system. The remainder of test period #2.4 (10 minutes total) and test period #2.5 (5 minutes) were cancelled.Pressure in the influent line rose from 38 psi at the beginning of test #2 to 55 psi when the test was aborted. The Alfa-Laval sediment discharge system was activated ("shot") twice during the test - once at 20 minutes into test #2, and again at 30 minutes. No samples of this effluent were captured.

TABLE 10: SURGE TANK SYSTEM AND LOGISTICS DATA

Separator Weight (lbs) (see note 1)	3600
Power System Weight (lbs) (see note 2)	None Required
Total System Weight (lbs)	**3600**
Separator Capacity (gpm) (see note 3)	**250**
System Weight to Capacity Ratio (lbs/gpm)	**14**
Separator Length (ft)	7.8
Separator Width (ft)	5.5
Separator Height (ft)	4.9
Separator Footprint Area (sq ft)	**42.9**

NOTES:

1. This is the empty weight of the surge tank. Assuming an operating volume of 1000 gallons, the operating weight of this system would be roughly 12,000 lbs.

2. No power system required for operation.

3. To expedite design, fabrication and procurement of a surge tank for the test program, it was decided to procure and modify an existing gravity separator with a 1000 gallon volumetric capacity, to provide a four minute resident time at the 250 gpm target flow rate. A Flo Trend IPL Phase[3] separator with a rated flow capacity of 100 gpm was procured and modified. The separator's coalescer plates were removed to increase flow capacity. Although the plates improve separation, they would significantly reduce the flow capacity of the unit, especially for thick and viscous emulsions, and were not needed to simulate a simple first stage surge tank. Because the separator was modified and then tested at 2.5 times the original rated capacity, the test results presented in this report for the surge tank should in no way be considered to reflect the performance of a production model Flo Trend separator.

TABLE 11:
SURGE TANK CRUDE OIL TEST SERIES
TEST RESULTS SUMMARY

Test Dates: 25 and 30 November 1992

Test #	INFLUENT PROPERTIES						OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Oil	$SG_{water} - SG_{oil}$	Oil Visc. (cP) (1),(a)	Emuls. Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	Oil Content (%)	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	244	29 ppm	N/A	N/A	N/A	9.9	91	38	102 ppm	N/A	152	62	0	9.6	62	N/A
2	230	5	(b)	(b)	(b)	10.7	76	33	14	(b)	154	67	3	N/A	68	40
3	271	25	0.136	336	1.5	3.8	1	< 1	100	0.6	271	100	25[c]	N/A	100	0
4	238	51	0.128	329	0.7	6.0	3	1	100	1.0	235	99	52	N/A	96	-2[d]
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	260	68 ppm	N/A	N/A	N/A	34.7	91	35	59 ppm	N/A	169	65	20 ppm	29.7	65	N/A
7	124	6	0.099	1360	9.1	8.8	40	32	22	6.3	84	68	5	N/A	68	11
8	76	4	(b)	(b)	(b)	34.7	13	16	24	2.9	64	84	5	N/A	83	-28[d]

(1) In oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency = (volume of water discharged through water effluent/volume of water in influent) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent oil content [ppm or %] - water effluent stream oil content [ppm or %])/influent oil content [ppm or %]) X 100

Notes on Data (correspond to superscripts in table):

(a) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 21° C for tests #2 through #4, 17° C for tests #7 and #8.
(b) Insufficient sample available for analysis.

(continued on next page)

TABLE 11: SURGE TANK CRUDE OIL TEST SERIES TEST RESULTS SUMMARY (continued)

Notes on Data (correspond to superscripts in table, continued):

(c) This data taken from 1 liter laboratory sample.

(d) Negative numbers here indicate greater percentage of oil in the water effluent than in the influent. See comment #4 below.

Comments and Observations:

1. Test #5 cancelled - separator unable to handle 100% oil at 250 gpm flow rates. Oil started seeping out from under the tank cover when the test was aborted.

2. Test #7 was at 50% capacity.

3. Test #8 was at 25% capacity.

4. Negative numbers for water purification efficiency indicate a larger percentage of oil in the water effluent line than in the influent. This could be due to the relatively long residence time for fluids in the separator (4 minutes), with oil building up from previous tests eventually being forced out the water effluent line.

5. During test #3, the hose leading from the oil effluent port of the separator to the oil effluent "surge tank" used in the test set-up was lifted to remove a vertical bend in the hose that impeded the flow of oil. Later, during test #4, one 10 foot section of this hose was removed. Both actions noticeably increased the flow of oil through this hose.

TABLE 12:
SURGE TANK SEA MOTION TEST SERIES
TEST RESULTS SUMMARY

Test Date: 30 November 1992

Test #	INFLUENT PROPERTIES						OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Oil (a)	SG_{oil}/SG_w	Oil Visc (cP) (1) (b)	Emuls Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	% Oil	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	249	148 ppm	N/A	N/A	N/A	102.0	13	5	0	N/A	236	95	107 ppm	60.0	94	N/A
2	285	18	0.133	1037	1.9	4.5	16	5	77	6.6	270	95	16	N/A	97	14
3	297	36	0.106	1029	1.3	3.5	0.4	0.1	100	2.9	297	100	37	N/A	98	-2[c]
4	217	52	0.088	768	1.4	14.1	6	3	100	1.8	211	97	51	N/A	100	3
5	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-

(1) In oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency = (volume of water discharged through water effluent/volume of water in influent) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent oil content [ppm or %] - water effluent stream oil content [ppm or %])/influent oil content [ppm or %]) X 100.

Notes on Data (correspond to superscripts in table):

(a) Calculated from a mass balance analysis using effluent stream data.
(b) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 17° C.
(c) Negative numbers here indicate a greater percentage of oil in the water effluent than in the influent. See comment #2 below.

(continued on next page)

TABLE 12: SURGE TANK SEA MOTION TEST SERIES TEST RESULTS SUMMARY (continued)

Comments and Observations:

1. Test #5 (100% oil influent) cancelled, after separator unable to perform at 250 gpm flow rates with 100% oil as observed during Standard Test Oil Test.

2. Negative numbers for water purification efficiency indicate a larger percentage of oil in the water effluent line than in the influent. This could be due to the relatively long residence time for fluids in the separator (4 minutes), with oil building up from previous tests eventually being forced out the water effluent line.

TABLE 13:
VORTOIL SYSTEM AND LOGISTICS DATA

Separator Weight (lbs)	7380
Power System Weight (lbs) (see note 1)	5540
Total System Weight (lbs)	**12920**
Separator Capacity (gpm) (see note 2)	**250**
System Weight to Capacity Ratio (lbs/gpm)	**52**
Separator Length (ft)	11.0
Separator Width (ft)	7.3
Separator Height (ft)	7.0
Separator Footprint Area (sq ft)	**79.8**

NOTES:

1. ESSM power system used for the tests consists of a hydraulic power unit (3840 lbs), one flow control block (180 lbs), and 2 hose reels each with 100 feet of 1 inch hose (760 lbs per reel with hose).

2. The maximum sustained flow rate observed during the tests was 280 gpm. 250 gpm is the manufacturer's rated capacity. A capacity of 280 gpm would give a weight to capacity ratio of 46 for the system.

TABLE 14:
VORTOIL MODIFIED CRUDE OIL TEST SERIES (INCLUDES SEA MOTION) TEST RESULTS SUMMARY

Test Dates: 2 and 3 December 1992

Test #	INFLUENT PROPERTIES						OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Oil (a)	SG_{oil}/SG_{w}	Oil Visc (cP) (1) (b)	Emuls Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	Oil Content (%) (d)	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	206[d]	37 ppm	N/A	N/A	N/A	7.1	0	0	N/A	N/A	206[d]	100	0	4.5	100	N/A
2	206[d]	4	(f)	(f)	3.6	3.9	8	4	100[e]	19.0	197	96	82 ppm	2.7	100	100
3.1	132	24	0.103	931	1.9	5.5	100	76	40	21.9	32	24	113 ppm	1.3	31	100
3.2	123	28	0.095	729	1.3	15.9	73	59	52	9.6	50	41	97 ppm	4.7	57	100
4	261	27	0.112	1003	3.3	4.6	98	38	100	31.4	162	62	178 ppm	1.4	85	100
5	258	76[f]	0.099	755	1.0	3.7	172	67	75	4.7	85	33	86	N/A	19	- 13[g]
6	235	20	0.133	996	3.8	1.8	52	22	100	18.9	184	78	2	N/A	96	92
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(1) In oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency = (volume of water discharged through water effluent/volume of water in influent) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent oil content [ppm or %] - water effluent stream oil content [ppm or %])/influent oil content [ppm or %]) X 100

Notes on Data (correspond to superscripts in table):

(a) Influent oil ratio calculated from a mass balance analysis of the most reliable data for this test.
(b) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 18° C.
(c). These oil/water ratios from 1 liter laboratory samples.

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TABLE 14: VORTOIL MODIFIED CRUDE OIL TEST SERIES (INCLUDES SEA MOTION) TEST RESULTS SUMMARY (continued)

Notes on Data (correspond to superscripts in table, continued)

(d) The water effluent flow rate and total flow rate for this test is low. The first stage surge tank in the system was not filled when the test was started, resulting in some of the influent water being used to displace the remaining air in the tank. There was no discharge through the oil effluent line (comes off the top of the surge tank) for this test.

(e) Very short duration of steady flow through the oil effluent line for this test allowed only data from one sample (of 11 planned) to be recorded for oil effluent stream for this test. Again, as in (d), the total flow may be low if the surge tank was not yet filled. The percentage of oil in the oil effluent shown in the table for this test is based on the one laboratory sample collected during the 11 minute test, and may not be accurate for the entire test period. See comment #3 on the next page for other comments regarding the oil effluent stream.

(f) Insufficient sample available for analysis.

(g) The disproportionate amount of oil in the water effluent produces this negative value. See comment #4 on page 2 regarding test #5 of this test.

Comments and Observations:

1. Test #3 was the reduced capacity test (target of 1/2 full capacity or 125 gpm for this separator). Test #3.1 was conducted with the Vortoil pump at reduced capacity, producing a longer residence time in the surge tank. Test #3.2 was conducted with the Vortoil pump at full capacity, recirculating more water in the system. These tests were set up this way in order to determine what effect, if any, the pump capacity had on system performance under the same influent conditions.

2. Test #6 was the sea motion test, at ± 15° at a period of 6.9 seconds. The influent oil ratio was modified from 50% to 25% target for this test to compare results to the other 25% oil influent tests conducted on this separator.

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TABLE 14: VORTOIL MODIFIED CRUDE OIL TEST SERIES (INCLUDES SEA MOTION) TEST RESULTS SUMMARY (continued)

Comments and Observations (continued):

3. The Vortoil system oil effluent stream is not steady, as it is dependent on a level control device inside the first stage surge/separation tank included in the system. The surging nature of the effluent oil stream also may allow for greater separation inside the surge tank when oil effluent flow is low or stopped. This could impact the reliability of a mass balance analysis that uses data collected over relatively short periods of time. The oil/water ratio data collected from this stream also was extremely unsteady over tests #3.1 and #3.2, with oil content varying from 100% to 42% under the same test conditions. Flow periodically stopped completely during these tests as well.

4. Test #5 was intended to be a 50% oil test at full capacity. There is conflicting data regarding the oil influent ratio. The 76% ratio shown is from a mass balance analysis, which matched well with the laboratory sample data (70%) for this test. Graduated cylinder data for this station averaged 36% over the test. It also was noted that it took an inordinate amount of time to reach what was believed to be a 50% oil mixture at the influent sampling station.

   During the first half of test #5, the water effluent samples were observed to be 100% oil. Samples from the Vortoil sampling port between the two suites of hydrocyclones showed low oil content as expected. Approximately 8 minutes into the test, the water effluent stream oil content abruptly dropped from 100% oil to an average of 6% oil for the next two minutes, and then to less than 1% for the remainder of the test. Vortoil representatives were not sure why this was happening.

   Immediately previous to test #5, the test was halted so that Vortoil personnel could install a check valve on the oil effluent line to prevent a siphoning effect on the discharge and any suction force on the surge tank.

5. Test #7 (100% oil) was cancelled because we ran out of oil after completing the other tests. During preparation for test #7, as the oil rate was increased towards 250 gpm, oil was not observed in the water effluent line. This matched our experience with 100% oil calibration runs conducted earlier in the week on the Vortoil system, where no effluent came through the water effluent line when the influent consisted of 100% oil.

TABLE 15: VORTOIL MOUSSE TEST SERIES TEST RESULTS SUMMARY

Test Date: 5 December 1992

	INFLUENT PROPERTIES						MOUSSE/OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
Test #	Flow Rate (gpm)	% Mousse (a)	SG__ / SG__	Mousse Visc (cP) (1) (b)	Emuls Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	Mousse/ Oil Content (%)	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Mousse/Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	215	35 ppm	N/A	N/A	N/A	21.0	0	0	N/A	N/A	215	100	214 ppm	11.1	100	N/A
2	217	15	(c)	(c)	(c)	30.2	30	14	99	72.2	187	86	122 ppm	6.9	100	100
3	212	27	0.090	27500	54.3	29.6	55	26	98	52.3	157	74	107 ppm	5.1	99	100
4	266	61	0.053	16995	57.7	18.5	165	62	98	53.1	101	38	103 ppm	5.1	96	100
5	191	100	N/A	33300	53.8	N/A	191	100	100	48.8	0	0	N/A	N/A	N/A	100

(1) In mousse/oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency for Mousse Tests = (volume of water discharged through water effluent/total volume of free water in both effluents) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent mousse content [ppm or %] - water effluent stream mousse/oil content [ppm or %])/influent mousse content [ppm or %]) X 100

Notes on Data (correspond to superscripts in table):

(a) Influent oil ratio derived from mass balance analysis using effluent stream data. For this test, all data was in good agreement. The derived influent mousse ratio was selected as the most reliable for this test.
(b) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 14° C.
(c) Insufficient sample available for analysis.

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TABLE 15: VORTOIL MOUSSE TEST SERIES TEST RESULTS SUMMARY (continued)

Comments and Observations:

1. During test #4, it was noted that the water effluent became progressively cleaner. It was reasoned that this may due to the water portion of the influent having more residence time in the first stage surge tank for preliminary separation before being processed in the hydrocyclones. The water has a longer residence time because the amount of water in the influent has decreased from the previous tests.

2. Some water flow was observed coming through the water effluent line for the first three minutes of test #5. This is assumed to be residual water in the system. The total volume was too small to be measured during this test.

3. No visual or quantitative indications of significant demulsification were observed during this test.

4. Mousse property data before and after separation is shown in the table on the following page.

TABLE 16:
VORTOIL MOUSSE TEST SERIES
MOUSSE PROPERTIES DURING TEST

Test Date: 5 December 1992

Test #	Percent Mousse in Influent	EMULSIFIED WATER VOLUME (%)				VISCOSITY (cP) (at Shear Rate = 10 sec^{-1})				SPECIFIC GRAVITY			
		Mousse Supply Line	Influent Mixture (Mousse/Oil Portion)	Mousse/Oil Effluent (Mousse/Oil Portion)	Change from Influent to Effluent	Mousse Supply Line @ 15°	Influent Mixture (Mousse/Oil Portion) @ 14° C	Mousse/Oil Effluent (Mousse/Oil Portion) @ 13° C	Change from Influent to Effluent	Mousse Supply Line	Influent Mixture (Mousse/Oil Portion)	Oil Effluent (Mousse/Oil Portion)	Change from Influent to Effluent
1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	15	55.9	(a)	72.2	(a)	27050	(a)	16750	(a)	0.950	(a)	0.945	(a)
3	27	60.5	54.3	52.3	- 2.0	25850	27500	24400	- 3100	0.928	0.937	0.916	- 0.021
4	61	54.9	57.7	53.1	- 4.6	32150	16995	19650	+ 2655	0.937	0.973	0.953	- 0.020
5	100	67.5	53.8	48.8	- 5.0	24800	33300	33050	- 250	0.899	0.915	0.919	+ 0.004

NOTES:

(a) Insufficient sample available for analysis.

TABLE 17:
VORTOIL MOUSE WITH EMULSION BREAKER TEST SERIES TEST RESULTS SUMMARY

Test Dates: 7 and 8 December 1992

	INFLUENT PROPERTIES						MOUSSE/OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
Test #	Flow Rate (gpm)	% Mousse	SG / SG	Mousse Visc (cP) (1),(a)	Emuls Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	Mousse/Oil Content (%)	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Mousse/ Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	208	84 ppm	N/A	N/A	N/A	4.0	0	0	0	N/A	208	100	84 ppm	2.7	100	N/A
2	263	25[b]	0.109	19050	55.0	0.6	57	22	99	38.9	206	78	2	N/A	100	90
3	280	26	0.092	15650	54.3	0.7	80	29	95	33.6	200	71	2	N/A	98	91
4	274	52	0.097	15700	45.7	0.7	161	59	95	59.6	114	41	3	N/A	93	95
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(1) In mousse/oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency for Mousse Tests = (volume of water discharged in water effluent stream/total volume of free water in both effluents) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent mousse/oil content [ppm or %] - water effluent stream mousse/oil content [ppm or %])/influent mousse/oil content [ppm or %]) X 100

Notes on Data (correspond to superscripts in table):

(a) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 13° C.
(b) Influent mousse ratio for this test taken from lab sample data and flow meter records. Influent graduated cylinder data for this test is suspect.

(continued on next page)

TABLE 17:
VORTOIL MOUSE WITH EMULSION BREAKER TEST SERIES TEST RESULTS SUMMARY (continued)

Comments and Observations:

1. For tests #2 and #3 (12/7/92 test date), the emulsion breaker EXXON Breaxit 7877 was added at a rate of 675 ml/min, corresponding to a dosage of 660 ppm to total flow. The emulsion breaker addition data for test #3 is suspect, which may explain the difference in separator performance for these two tests where the other influent conditions are nearly equal. For test #4 (12/8/92 test date), Breaxit 7877 was added at a rate of 440 ml/min, corresponding to a dosage of 440 ppm of the total flow. The peristaltic pump may have needed re-calibration for the higher line pressures associated with the 50% mousse influent on test #4, resulting in the lower dosage rate of emulsion breaker for this test.

2. Test #3 was intended to be a 5% mousse influent test - difficulty in reading the oil/water ratio at low mousse contents with the emulsion breaker added, along with flow meter problems in the mousse supply line at low flow rates, are assumed to be the cause of the error.

3. Test #5 (100% mousse) was cancelled due to limitations of the testing equipment (unable to pump mousse effluent on 12/8/92).

4. It was difficult to collect oil effluent samples for graduated cylinder readings during this test, and the numbers shown in the table were based on visual estimation of the water content as seen in the oil effluent stream. The estimates compared well with the laboratory sample that was collected during test #3.

5. Mousse property data before the addition of the emulsion breaker, after mixing, and after separation is shown in the table on the following page.

TABLE 18:
VORTOIL MOUSSE WITH EMULSION BREAKER TEST SERIES MOUSSE PROPERTIES DURING TEST

Test Dates: 7 and 8 December 1992

Test #	Percent Mousse in Influent	EMULSIFIED WATER VOLUME (%)				VISCOSITY (cP) (at Shear Rate = 10 sec^{-1})				SPECIFIC GRAVITY			
		Mousse Supply Line	Influent Mixture (Mousse/Oil Portion), (a)	Mousse/ Oil Effluent (Mousse/Oil Portion)	Change from Influent to Effluent	Mousse Supply Line @ 15° C	Influent Mixture (Mousse/Oil Portion),(a) @ 13° C	Mousse/ Oil Effluent (Mousse/Oil Portion) @ 13° C	Change from Influent to Effluent	Mousse Supply Line	Influent Mixture (Mousse/Oil Portion),(a)	Mouuse/Oil Effluent (Mousse/Oil Portion)	Change from Influent to Effluent
	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	25	41.3	55.0	38.9	- 16.1	24000	19050	4575	- 14475	0.938	0.917	0.913	- 0.004
3	26	68.5	54.3	33.6	- 20.7	23500	15650	1781	- 13869	0.933	0.934	0.921	- 0.013
4	52	54.5	45.7	59.6	+ 13.9	20050	15700	3879	- 11821	0.940	0.926	0.931	+ 0.005
5	-	-	-	-	-	-	-	-	-	-	-	-	-

NOTES:

(a) Includes effect of emulsion breaker. Emulsion breaker added upstream of influent sampling station.
(b) Insufficient sample available for analysis.

TABLE 19: VORTOIL DEBRIS TEST SERIES TEST RESULTS SUMMARY

Test Date: 9 December 1992

Test #	INFLUENT PROPERTIES						OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Oil (a)	SG_{oil}/SG_w	Oil Visc (cP) (1)(b)	Emuls Water Vol % (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	Oil Content (%) (c)	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	196	7 ppm	N/A	N/A	N/A	99.7	0	0	N/A	N/A	196	100	57 ppm	163.6	100	N/A
2.1	220	55	0.095	1210	4.8	2.4	163	74	80	16.7	57	26	13	N/A	50	76
2.2	228	55	0.102	983	3.5	2.5	142	62	90	34.9	85	38	3	N/A	81	95
2.3	218	55	0.104	1064	2.0	2.2	143	66	84	9.6	75	34	14	N/A	66	75
2.4	227	60	0.107	1140	2.7	2.2	153	68	90	8.5	74	32	9	N/A	74	85
2.5(d)	237	56(e)	0.109	(e)	(e)	1.9	151	64	92	(e)	85	36	3	N/A	80(e)	95
2(avg)	224	56	0.103	1110	3.2	2.3	151	67	86	15.8	73	33	10	N/A	66	83

(1) In oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency = (volume of water discharged through water effluent/volume of water in influent) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent oil content [ppm or %] - water effluent stream oil content [ppm or %])/influent oil content [ppm or %]) X 100

Notes on Data (correspond to superscripts in table):

(a) Lab sample data used for influent and effluent oil ratios for this test; graduated cylinder data are suspect.
(b) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 18° C.
(c) Calculated from a mass balance analysis using the most reliable data from this test.
(d) Test was stopped 3 minutes into this 5 minute test period. See comment #4 below.

(continued on next page)

TABLE 19:
VORTOIL DEBRIS TEST SERIES
TEST RESULTS SUMMARY (continued)

Notes on Data (correspond to superscripts in table, continued):

(e) No laboratory samples were taken for this test period before the test was aborted. Average influent oil ratio values from the previous test periods were used to estimate water removal efficiency.

Comments and Observations:

1. Debris was added at a rate of 0.25 lb/min over test #2. The debris mixture consisted of 10% by weight 1/4 inch wood shavings, 10% #10 mesh size sawdust, 40% #40 mesh size sawdust and 40% #140 mesh size sawdust.

2. The intended oil influent ratio was 25% for all of test #2, and the target total flow rate was 250 gpm for the entire test.

3. The total time that debris was fed to the separator for this test was approximately 42 minutes. The test was interrupted several times due to problems with the testing equipment.

4. Vortoil system under debris conditions was limited by the pressure differential across the simplex strainer in the system. During the test, the pressure differential gradually increased. At 28 minutes into the test, the differential pressure had risen to 2 psi, but was still at 2 psi after 33 minutes total. At 39 minutes, the pressure differential was at 7-8 psi, and after 43 minutes was 18 psi. At this time, the test was stopped due to problems with the testing equipment. When we started the test again, the reading was 18 psi with only water. When the oil was added, the pressure increased to 20 psi, and the test was stopped as this was the limiting pressure differential recommended by the manufacturer of the strainer. Vortoil personnel said that the test could go on, but that the strainer would be damaged.

(continued on next page)

TABLE 19: VORTOIL DEBRIS TEST SERIES TEST RESULTS SUMMARY (continued)

Comments and Observations (continued):

(Item 4 continued:)

It also must be noted that the following day, when modifying the test set-up for the next set of tests, a large amount of oily debris was found in some of the piping well upstream of the separator. The total amount of oily debris was estimated at approximately 10 gallons, although no dry weight of the debris content was measured. This indicates that the separator probably would have reached a limiting pressure sooner, if the full amount of debris added to the influent had made it to the separator.

TABLE 20:
INTR-SEPTOR 250 SYSTEM AND LOGISTICS DATA

Separator Weight (lbs) (see note 1)	2404
Power System Weight (lbs) (see note 2)	3000
Total System Weight (lbs)	**5404**
Separator Capacity (gpm) (see note 3)	**155**
System Weight to Capacity Ratio (lbs/gpm)	**35**
Separator Length (ft)	5.9
Separator Width (ft)	3.5
Separator Height (ft)	5.0
Separator Footprint Area (sq ft)	**20.6**

NOTES:

1. Separator weight shown was measured with 20 hp motor. The 20 hp motor was replaced with a 40 hp motor after the weight had been taken in order to increase both the flow capacity of the system and its ability to handle fluids with higher viscosities. The separator never performed at its quoted flow capacity of 250 gpm.

2. Weight of ESSM 30 kW generator. Another more mobile generator was used during the tests, but this generator is more representative of what actually would be required to run the separator system. This generator is lighter than the one used for the tests, but would provide ample power for the system.

3. Highest sustained flow rate observed during tests.

TABLE 21:
INTR-SEPTOR 250 MODIFIED CRUDE OIL TEST (INCLUDES SEA MOTION) TEST RESULTS SUMMARY

Test Date: 14 December 1992

	INFLUENT PROPERTIES						OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
Test #	Flow Rate (gpm)	% Oil (a)	SG / SG	Oil Visc. (cP) (1),(b)	Emuls. Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	% Oil	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	133	27 ppm	N/A	N/A	N/A	11.9	90	68	0	N/A	43	32	86 ppm	10.9	32	N/A
2	119	21	0.140	(c)	7.3	10.0	89	75	27	6.0	30	25	3	N/A	30	86
3	119	65	0.090	1210	2.0	4.1	85	71	99[d]	10.2	35	29	3	N/A	98	95
4	123	61	0.083	1211	3.4	3.3	91	74	85[d]	5.4	32	26	2	N/A	70	96
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	109	59	0.102	1305	1.2	3.5	84	77	80[d]	5.4	26	23	2	N/A	60	96

(1) In oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency = (volume of water discharged through water effluent/volume of water in influent) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent oil content [ppm or %] - water effluent stream oil content [ppm or %])/influent oil content [ppm or %]) X 100

Notes on Data (correspond to superscripts in table):

(a) Influent oil ratio calculated from mass balance equations using the most reliable data for this test.
(b) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 17° C.
(c) Insufficient sample available for analysis.
(d) From lab sample data.

(continued on next page)

TABLE 21: INTR-SEPTOR 250 MODIFIED CRUDE OIL TEST (INCLUDES SEA MOTION) TEST RESULTS SUMMARY (continued)

Comments and Observations:

1. Separator unable to operate at 250 gpm, independent of fluid mixture. Unit was tested at a target maximum flow rate of 125 gpm.

2. Test #3 was intended to be a reduced capacity test - poor ability to monitor influent flow rates resulted in test being no lower capacity that any other test in this series.

3. Test #5 (50% target oil influent) cancelled - separator unable to handle the ratio. Drew large amount of power from generator. System shut off by Inter-Septor personnel. Because no laboratory sample was taken, we have no data to verify at what oil ratio the separator reaches its limit. For this test, influent sample graduated cylinder readings were considerably lower than other data indicated. Because the influent graduated cylinder readings were at approximately 50% when the separator was turned off, and they are believed to be low, the actual oil ratio in the influent may have been 75% or higher.

4. Test #6 was the sea motion test at $\pm$ 15° amplitude and a period of 7.25 seconds.

TABLE 22: INTR-SEPTOR 250 MOUSSE TEST SERIES TEST RESULTS SUMMARY

Test Date: 15 December 1992

Test #	INFLUENT PROPERTIES						MOUSSE/OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Mousse	SG___ / SG___	Mousse Visc (cP) (1) (a)	Emuls Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	Mousse/Oil Content (%) (b)	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Mousse/Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	128	0	N/A	N/A	N/A	5.9	79	62	0	N/A	48	38	119 ppm	5.3	38	N/A
2	134	6	(c)	(c)	70 7	8.8	80	60	3	(c)	53	40	3	N/A	40	51
3	155	26	0.099	(c)	68.3	10.3	90	47	34	73.5	66	42	14	N/A	54	46
4	154	52	0.102	26300	59.8	5.4	87	56	71	59.7	69	44	27	N/A	71	48
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(1) In mousse/oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency for Mousse Tests = (volume of water discharged through water effluent/total volume of free water in effluents) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent mousse content [ppm or %] - water effluent stream mousse/oil content [ppm or %])/influent mousse content [ppm or %]) X 100

<u>Notes on Data (correspond to superscripts in table)</u>:

(a) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 16° C.
(b) Oil effluent oil ratio calculated from mass balance equations using the most reliable data for this test.
(c) Insufficient sample available for analysis.

(continued on next page)

TABLE 22: INTR-SEPTOR 250 MOUSSE TEST SERIES TEST RESULTS SUMMARY (continued)

Comments and Observations:

1. Test #5 was cancelled (100% mousse test). Test equipment pump used to transfer oil effluent was unable to handle the emulsion. During test #5 preparation, when 100% mousse was being pumped, and before the test was aborted, it was observed that the separator was able to handle the 100% mousse. This was a very short time, however, and does not indicate the separator's ability to handle a viscous emulsion for periods longer than one or two minutes.

2. There was no visual or quantitative indication that any significant amount of the emulsion was being broken due to the separator during any of the tests.

3. Mousse property data before and after separation is shown in the table on the following page.

TABLE 23:
INTR-SEPTOR MOUSSE TEST SERIES MOUSSE PROPERTIES DURING TEST

Test #	Percent Mousse in Influent	EMULSIFIED WATER VOLUME (%)				VISCOSITY (cP) (at Shear Rate = 10 sec^{-1})				SPECIFIC GRAVITY			
		Mousse Supply Line	Influent Mixture (Mousse/Oil Portion)	Mousse/Oil Effluent (Mousse/Oil Portion)	Change from Influent to Effluent	Mousse Supply Line @ 18° C	Influent Mixture (Mousse/Oil Portion) @ 16° C	Mousse/Oil Effluent (Mousse/Oil Portion) @ 14° C	Change from Influent to Effluent	Mousse Supply Line	Influent Mixture (Mousse/Oil Portion)	Mousse/Oil Effluent (Mousse/Oil Portion)	Change from Influent to Effluent
1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	6	70.7	(a)	(a)	(a)	29250	(a)	(a)	(a)	0.911	(a)	(a)	(a)
3	26	73.3	68.3	73.5	+ 5.2	35900	(a)	31900	(a)	0.952	0.926	0.985	+ 0.059
4	52	58.0	59.8	59.7	- 0.1	17550	26300	24450	- 1850	0.934	0.920	0.933	+ 0.013
5[b]	-	-	-	-	-	-	-	-	-	-	-	-	-

NOTES:

(a) Insufficient sample available for analysis.
(b) Test #5 (100% mousse) cancelled - see comment #1 on Table 22 (previous page).

TABLE 24:
INTR-SEPTOR 250 MOUSSE WITH EMULSION BREAKER TEST SERIES TEST RESULTS SUMMARY

Test Date: 16 December 1992

Test #	INFLUENT PROPERTIES						MOUSSE/OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Mousse (a)	SG / SG	Mousse Visc (cP) (1) (b)	Emuls Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	Mousse/Oil Content (%)	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Mousse/Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	131	10 ppm	N/A	N/A	N/A	18.1	78	59	0	N/A	53	41	16 ppm	18.5	41	N/A
2	129	4	(c)	(c)	59.4	1.3	83	64	9	64.2	47	36	1	N/A	38	75
3	132	39	0.096	17050	70.9	1.3	93	70	51	66.7	40	30	1	N/A	46	98
4	138	57	0.106	10600	53.7	0.8	101	73	66	44.4	38	27	1	N/A	52	98
5	172	100	N/A	229	52.8	N/A	102	60	97	54.7	68	40	26[d]	N/A	95[d]	74[d]

(1) In mousse/oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency for Mousse Tests = (volume of water discharged through water effluent/total volume of free water in effluents) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent mousse/oil content [ppm or %] - water effluent stream mousse/oil content [ppm or %])/influent mousse/oil content [ppm or %]) X 100

Notes on Data (correspond to superscripts in table):

(a) Calculated from mass balance analysis for tests #2 through #4.
(b) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 16° C.
(c) Insufficient sample available for analysis.
(d) Water effluent oil content data from the graduated cylinders, lab samples, and mass balance analysis conflicted considerably for this test. Graduated cylinder data was used for the efficiency calculations, producing higher efficiencies than the data from the other sources. Because there was no definite indication of which data was

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TABLE 24: INTR-SEPTOR 250 MOUSSE WITH EMULSION BREAKER TEST SERIES TEST RESULTS SUMMARY (continued)

Notes on Data (correspond to superscripts in table, continued):

(Item (d) continued:)

most likely correct, the benefit of the doubt was given to separator performance and graduated cylinder data was used for analysis.

Comments and Observations:

1. The emulsion breaker EXXON Breaxit 7877 was added at a rate of 290 ml/min, corresponding to a dosage of 540 ppm of the total flow for each test.

2. Test #5 (100 % mousse with emulsion breakers) was aborted at 9 minutes due to limitations of the separator (began to draw too much amperage). During this test, the flow rate was gradually reduced to overcome high line pressures. The 172 gpm is an average over the test, as are other flow rate data shown. Due to flow rate monitoring and hence control problems, the actual flow rate turned out to be significantly higher than anticipated. The test may have been completed successfully if the flow rate had been controlled at the lower target rate of approximately 125 gpm for this separator.

3. It could be visually observed that the emulsion was being broken during all tests in this series. However, after breaking the mousse, a significant amount of the de-emulsified water was still discharged through the oil effluent line. This is represented in the values for water removal efficiency shown in the table above.

4. Mousse property data before the addition of the emulsion breaker, and before and after separation is shown in the table on the following page.

TABLE 25: INTR-SEPTOR MOUSSE WITH EMULSION BREAKER TEST SERIES MOUSSE PROPERTIES DURING TEST

Test #	Percent Mousse in Influent	EMULSIFIED WATER VOLUME (%)				VISCOSITY (cP) (at Shear Rate = 10 sec^{-1})				SPECIFIC GRAVITY			
		Mousse Supply Line	Influent Mixture (Mousse/Oil Portion) (a)	Mousse/ Oil Effluent (Mousse/Oil Portion)	Change from Influent to Effluent	Mousse Supply Line @ 17° C	Influent Mixture (Mouse/Oil Portion) (a) @ 16° C	Mousse/ Oil Effluent (Mousse/Oil Portion) @ 16° C	Change from Influent to Effluent	Mousse Supply Line	Influent Mixture (Mousse/Oil Portion) (a)	Mousse/Oil Effluent (Mousse/Oil Portion)	Change from Influent to Effluent
1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	4	56.0	59.4	64.2	+ 4.8	33400	(b)	98	(b)	0.942	(b)	0.964	(b)
3	39	62.2	70.9	66.7	- 4.2	30350	17050	1960	- 15090	0.933	0.927	0.927	0.000
4	57	62.5	53.7	44.4	- 9.3	31700	10600	4675	- 5925	0.931	0.919	0.897	- 0.022
5	100	55.6	52.8	54.7	+ 1.9	33000	229	1392	+ 1163	0.927	0.889	0.879	- 0.010

NOTES:

(a) Includes effect of emulsion breaker. Emulsion breaker added upstream of influent sampling station.
(b) Insufficient sample available for analysis.

TABLE 26:
INTR-SEPTOR 250 DEBRIS TEST SERIES TEST RESULTS SUMMARY

Test Date: 17 December 1992

Test #	INFLUENT PROPERTIES						OIL EFFLUENT STREAM				WATER EFFLUENT STREAM				EFFICIENCY	
	Flow Rate (gpm)	% Oil (a)	SG_{oil}/SG_w	Oil Visc (cP) (1) (b)	Emuls Water Vol (%) (1)	Mean Droplet Size (mic) (2)	Flow Rate (gpm)	% of Total Flow	% Oil	Emuls. Water Vol (%) (1)	Flow Rate (gpm)	% of Total Flow	Oil Content (%)	Mean Droplet Size (mic) (2)	Water Removal Effic. (%) (3)	Hydro-carbon Removal Effic. (%) (4)
1	117	39 ppm	N/A	N/A	N/A	4.1	84	72	0	0	33	28	0	3.5	28	N/A
2.1	121	50	0.101	706	1.6	12.6	86	71	67	3.2	35	29	5	N/A	55	90
2.2	109	53	0.094	510	1.5	2.1	80	73	64	2.4	29	27	7	N/A	53	88
2.3	120	50	0.101	419	1.0	3.7	76	64	74	2.3	44	36	7	N/A	68	86
2.4	110	56	0.106	424	0.9	3.0	72	66	77	3.6	38	34	6	N/A	73	88
2.5	99	61	(c)	(c)	(c)	(c)	70	71	80	(c)	29	29	6	N/A	71	90
2 (avg)	113	53	0.102	514	1.3	5.4	77	69	72	2.9	35	31	6	N/A	63	88

(1) In oil portion of sample.
(2) In free water portion of sample.
(3) Water Removal Efficiency = (volume of water discharged through water effluent/volume of water in influent) X 100.
(4) Hydrocarbon Removal Efficiency = ((influent oil content [ppm or %] - water effluent stream oil content [ppm or %])/influent oil content [ppm or %]) X 100

Notes on Data (correspond to superscripts in table):

(a) Influent oil ratio calculated from mass balance equations using the most reliable data for this test.
(b) Viscosity measurements taken at shear rate = 10 sec^{-1}, at an average sample temperature of 20° C.
(c) Insufficient sample available for analysis.

(continued on next page)

TABLE 26: INTR-SEPTOR 250 DEBRIS TEST SERIES TEST RESULTS SUMMARY (continued)

Comments and Observations:

1. Debris was added at a rate of 0.125 lbs per minute over the 45 minute test #2 (test periods #2.1 through #2.4 were 10 minutes in length, test period #2.5 was five minutes in length). The debris mixture consisted of 10% by weight 1/4 inch wood shavings, 10% #10 mesh size sawdust, 40% #40 mesh size sawdust, and 40% #140 mesh size sawdust.

2. The target oil ratio for the influent for this test was 25% oil. The values for influent oil ratio shown were derived from mass balance calculations using the oil and water effluent oil/water ratios.

TABLE 27:
SEPARATOR COMPARISON: SYSTEM CAPACITY AND LOGISTICS CHARACTERISTCS

	Alfa-Laval	Surge Tank	Vortoil	Intr-Septor	Target Specifications
Principle of Operation	Disk-Stack Centrifuge	Gravity Tank	Hydrocyclone	Centrifuge	N/A
Capacity (gpm)	65	250	250	155	250 - 500
System Weight (lbs)	16,800	3,600	12,920	5,404	4000 - 6000
Weight to Capacity Ratio (lbs/gpm)	258	14	52	35	8 - 24
System Footprint (ft^2)	114	43	130	41	25
System Volume (ft^3)	1080	214	769	195	125

TABLE 28:
SEPARATOR PERFORMANCE COMPARISON: CRUDE OIL TEST SERIES

	Alfa-Laval	Surge Tank	Vortoil	Intr-Septor
Hydrocarbon Removal Efficiency	100% throughout	0% to 40% range 13% average	100% for ≤28% oil in influent*	86% to 96% 93% average
Average Oil Content in Water Effluent Stream	149 ppm for Influent Oil less than 100%	27%	130 ppm*	2.5%
Water Removal Efficiency	63% to 80% 73% average	62% to 100% 82% average	31% to 100% 95% average	30% to 98% 58% average
Impact of Increased Oil Content in Influent	Improves water removal performance No impact to hydrocarbon removal performance	Improves water removal performance Significantly degrades hydrocarbon removal performance	Small drop in water removal performance Significant degradation in hydrocarbon removal performance observed at 76% Oil influent*	Moderate improvement in water removal performance Small improvement in hydrocarbon removal performance

* See Text or Table 14 regarding Vortoil 76% Oil Influent test - poor results are suspected to be non-representative of separator performance and are included in numerical data presetned in this table.

TABLE 29:
SEPARATOR PERFORMANCE COMPARISON:
IMPACT OF 100% WATER OIL, OR MOUSE INFLUENTS, TENDENCY FOR EMULSIFICATION, AND IMPACT OF SEA MOTION AND REDUCED CAPACITY

	Alfa-Laval	Surge Tank	Vortoil	Intr-Septor
Ability to Handle 100% Water Influent	36% of flow out oil effluent (average)	26% of flow out oil effluent (average)	Excellent: No flow through oil or mousse effluent stream	65% of flow out oil effluent (average)
Ability to Handle 100% Oil or Mousse Influent	59% of flow out water effluent	Beyond limits of separator.	Excellent. No flow through water effluent stream.	Beyond limits of separator (could handle 100% mousse + emulsion breaker, not tested with 100% mousse alone)
Emulsification Resulting from Separation (Crude Oil Test Series)	Insignificant	Insignificant	Substantial: Influent at 2.5%, to effluent at 17.6% (averages)	Small: Influent at 3.5%, to effluent at 6.8% (averages)
Impact of Sea Motion	No Impact	No Impact	Small Drop in Hydrocarbon Removal Performance Observed	Slight Drop in Water Removal Performance Observed
Impact of Reduced Capacity	NOT TESTED	Small increase in water removal efficiency Significant reduction in hydrocarbon removal performance	Significant impact to water removal efficiency No impact to hydrocarbon removal performance	NOT TESTED

TABLE 30: SEPARATOR PERFORMANCE COMPARISON: MOUSSE TEST SERIES

	Alfa-Laval	Surge Tank	Vortoil	Intr-Septor
Impact of Mousse on Performance (as compared to Crude Oil Test)	Hydrocarbon removal performance slightly degraded at 50% mousse Water removal efficiency moderately decreased	NOT TESTED	Hydrocarbon removal performance slightly improved Water removal slightly improved	Hydrocarbon removal performance significantly degraded Water removal slightly improved
Change in Water Content of Emulsion After Separation	Slight: From 63% in influent to 59% in effluent (averages)	NOT TESTED	Slight: From 60% in influent to 57% in effluent (averages)	No Change: 67% influent and effluent (averages)

TABLE 31: SEPARATOR PERFORMANCE COMPARISON: MOUSSE WITH EMULSION BREAKER TEST SERIES

	Alfa-Laval	Surge Tank	Vortoil	Intr-Septor
Impact of Emulsion Breaker on Performance, as Compared to Mousse Test	No significant impact - Very small drop in water purification efficiency	NOT TESTED	Small drop in water removal efficiency Small drop in water purification efficiency	Moderate reduction in water removal efficiency Significant improvement in water purification
Change in Water Content of Emulsion Remaining After Separation	Substantial: 68% in influent, to 46% in effluent (averages)	NOT TESTED	Moderate: 52% in influent, to 44% in effluent (averages)	Insignificant: 59% in influent, to 58% in effluent (averages)
Average Change in Viscosity After Separation	81% reduction in viscosity	NOT TESTED	85% reduction in viscosity	94% reduction in viscosity

TABLE 32: SEPARATOR PERFORMANCE COMPARISON: DEBRIS TEST SERIES

	Alfa-Laval	Surge Tank	Vortoil	Intr-Septor
Impact of Debris on System Operation	33 minutes of debris addition before test stopped at request of Alfa-Laval personnel	NOT TESTED	43 minutes of debris addition before test stopped due to potential for damage to system	No negative impact to system operability (45 minutes of debris addition)
Impact of Debris on Water Removal Performance	Significant increase in water removal efficiency compared to other tests 91% efficiency	NOT TESTED	Significant drop in water removal efficiency compared to other tests 60% efficiency	Small drop in water removal efficiency compared to Standard Oil and Mousse Tests 63% efficiency
Impact of Debris on Hydrocarbon Removal Performance	Significant reduction in water purity with time 68% efficiency 15% oil in water effluent (average)	NOT TESTED	Moderate drop in water purification efficiency (but may be due to higher oil content) 83% efficiency 10% oil in water effluent (average)	Small decrease in water purification efficiency 88% efficiency 6% oil in water effluent (average)

APPENDIX A: TEST PLAN MATRICES

Crude Oil Test Series Test Matrix					
		Influent			
Test #	Flow Rate	% Oil	% H_2O	Duration (min)	Notes:
1	Full	0%	100%	10	
2	Full	5%	95%	10	
3	Full	25%	75%	10	
4	Full	50%	50%	10	
5	Full	100%	0%	10	
6	Full	0%	100%	10	
7	50% Capacity	5%	95%	10	Reduced Capacity: 50%
8	25% Capacity	5%	95%	10	Reduced Capacity: 25%

Crude Oil Test Series Test Matrix (modified)					
		Influent			
Test #	Flow Rate	% Oil	% H_2O	Duration (min)	Notes:
1	Full	0%	100%	10	
2	Full	5%	95%	10	
3	50% Capacity	25%	75%	10	50% capacity
4	Full	25%	75%	10	
5	Full	50%	50%	10	
6	Full	50%	50%	10	Sea Motion
7	Full	100%	0%	10	

Sea Motion Test Series Test Matrix					
Test #	Flow Rate	Influent		Duration (min)	Notes:
		% Oil	% H_2O		
1	Full	0%	100%	10	All phases at ±15° at 7 sec
2	Full	5%	95%	10	
3	Full	25%	75%	10	
4	Full	50%	50%	10	
5	Full	100%	0%	10	
6	Full	0%	100%	10	This phase deleted in later tests

Mousse Test Series Test Matrix					
Test #	Flow Rate	Influent		Duration (min)	Notes:
		% Mousse	% H_2O		
1	Full	0%	100%	10	
2	Full	5%	95%	10	
3	Full	25%	75%	10	
4	Full	50%	50%	10	
5	Full	100%	0%	10	
6	Full	0%	100%	10	This phase deleted in later tests.

Mousse With Emulsion Breaker Test Series Test Matrix					
Test #	Flow Rate	Influent		Duration (min)	Notes:
		% Mousse	% H_2O		
1	Full	0%	100%	10	
2	Full	5%	95%	10	Phases 2 through 5 conducted with emulsion breaker added to influent stream
3	Full	25%	75%	10	
4	Full	50%	50%	10	
5	Full	100%	0%	10	
6	Full	0%	100%	10	This phase deleted in later tests.

Debris Test Series Test Matrix					
Test #	Flow Rate	Influent		Duration (min)	Notes:
		% Oil	% H_2O		
1	Full	0%	100%	10	
2	Full	25%	75%	45	Debris added at throughout Phase 2